Manual for Non-Destructive Testing of Rail

ETG-01-03

Applicability

ARTC Network Wide SMS

Publication Requirement

Internal / External

Primary Source

ETN-01-04

Document Status

Version #	Date Reviewed	Prepared by	Reviewed by	Endorsed	Approved
1.0	28 Mar 24	Standards	Stakeholders	Manager Track & Civil Standards	Head of Engineering Standards 15/04/2024

Amendment Record

Amendment Version #	Date Reviewed	Clause	Description of Amendment
1.0	28 Mar 24	Various	Renumbered from ETN-01-04. Document references updated throughout. Added reference defect table for new welds. Removed diagram re: locations within turnouts to be tested as this does not align with ETA-01-05.

Table of Contents

1 Introduction

1.1 Purpose

This Engineering Manual details the:

- Equipment requirements for ultrasonic rail testing
- Daily Calibration requirements of ARTC ultrasonic rail testing equipment
- Procedures for Manual Ultrasonic Testing of
- Rail
- Rail welds
- Head repair welds
- Turnouts: Switches and Crossings [1]
- Sizing and definition of defects
- Recording and Reporting Methods of the test and calibration results
- Periodic Calibration requirements of ARTC ultrasonic rail equipment
- Other NDT methods

Testing Frequencies are detailed in ETA-01-05 Non-Destructive Testing of Rail.

1.2 Scope

This standard applies to all track, including turnouts, where detailed inspection of rails and welds is carried out as per ETS-01-00.

This standard also applies in tracks where, although detailed inspection is not mandated, an ad hoc inspection has been directed by corridor management due to condition or operating circumstance.

1.3 Document Owner

The Head of Engineering Standards is the Document Owner. Queries should be directed to standards@artc.com.au in the first instance.

1.4 Parent Document

This Guideline supports ETA-01-05 Non-Destructive Testing of Rail.

1.5 Definitions

The following terms and acronyms are used within this document:

[1] Except Manganese Crossings which cannot be ultrasonically tested due to the material properties. These are to be visually examined and tested as specified in TMS 11.

TERM OR ACRONYM	DESCRIPTION
BWE	Back Wall Echo
FSH	Full Screen Height
HAZ	Heat Affected Zone
IB	Inclusion Band
NDT	Non-Destructive Testing
RCF	Rolling Contact Fatigue
SDH	Side Drilled Hole
TD	Transverse Defect
VSH	Vertical Split Head

2 Part A – General Requirements

2.1 Personnel Qualifications

2.1.1 Non-Destructive Testing Qualifications

Non-Destructive testing shall only be carried out by ARTC Certificated personnel who have been assessed as competent, by a Qualified Level III trainer, working within a registered training organisation, to:

- (For Ultrasonic testing) carry out the testing methods described in ETG-01-03 Manual for Non-Destructive Testing of Rail: All Sections.
- (For Dye Penetrant testing) carry out the duties described in ETG-01-03 Manual for Non-Destructive Testing of Rail: Section 5.7.2.
- For all other methods, as approved by Manager Track & Civil Standards.

Assessment should conform to AS 3998 Non-Destructive Testing – Qualification and Certification of Personnel.

Note: *A rail specific NDT course has been developed by ARTC. This course is based on the experience, training and competency assessment requirements stated in* ETP-00-01 Written Practice for the Training Competency Assessment and Certification of Personnel in Non-Destructive Testing to SNT-TC-1A (2001 Edition)*. Certification from this course meets the competency requirements of 2.1*

2.1.2 Visual Capability

All Ultrasonic testers must be able to:

- Read a Jaeger Number 1 Chart at a distance of not less than 305mm
- Be capable of distinguishing and differentiating contrast between colours and shades of grey used in the method.

All Ultrasonic testers shall be visually checked annually.

Note: *These competencies are in addition to other ARTC requirements for items like Safeworking, medical requirements, etc.*

2.1.3 Records

Records shall be kept with respect to each certification of:

- Name of certified employee
- Level of certification method
- Procedures in which they have been assessed competent
- Examination results (Pass/Fail)
- Competency assessment tool
- Dates of certification
- Signature of Employer's Representative

2.1.4 Re-Certification

Certified employees shall be re-certified at intervals of no more than 3 years for SNT Levels I and II and 5 years for SNT Level III. Re-certification may be made on the basis of continued satisfactory performance but for SNT Levels I and II it must include a practical, Performance Checklist in the relevant method.

Re-certification may be undertaken at any time at the discretion of the employer where the scope of work changes, there is concern that performance has deteriorated or technological change necessitates re-certification. Where an employee has had no practical hands-on-experience for more than 6 months, re-certification should be undertaken before the team member resumes testing activity.

As a result of such re-certification, the Tester's certification may be extended or revoked.

Note: 'ARTC Ultrasonic Levels I, II, and III' are defined in ETP-00-01 Written Practice for the Training Competency Assessment and Certification of Personnel in Non-Destructive Testing to SNT-TC-1A (2001 Edition)

3 Equipment

3.1 Ultrasonic Flaw detectors

The ultrasonic testing equipment shall employ A-scan presentation and shall have a reserve sensitivity of at least 20 dB at the maximum beam path used. The equipment and probes shall be capable of operation within a frequency range of 2MHz to 6MHz.

Instrumentation may be digital or analogue. Digital units may have calibrations stored in the database and recalled as needed, in which case the calibration should be checked before use. The frequency at which these calibrations need to be documented is set out in section *4.2*.

The use of other equipment types will be considered if the user can demonstrate, using known defects, that the equipment is at least as efficient at detecting internal defects as the above equipment.

3.2 Ultrasonic Probes

Error! Reference source not found. describes the ultrasonic probes specified for testing in ARTC. The ultrasonic inspector should carry all six probes.

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NAME	SHAPE & SIZE	MEASUREMENT ANGLE	SIGNAL FREQUENCY
Probe 1 Single 70˚	14x14mm to 20x22mm	70°	2.0 – 2.5 MHz
Probe 2 35˚	14x14mm to 20x22mm	38°	2.0 – 2.5 MHz
Probe 3 Single 0˚	24mm diameter	0°	2.0 – 2.5 MHz
Probe 4 [2] Twin Crystal 0˚	7x18mm	0°	2.0 - 2.5 MHz
Probe 5 Small 0˚	10mm diameter	0°	4.0 – 5.0 MHz
Probe 6 Single Crystal 70˚ Or Twin Crystal 70˚	10 x 10mm Or 3.5 x 10mm	70°	4.0 - 5.0 MHz

Notes:

1 *These probes are specified to standardise current probe usage: refer to section 4.1 of ETA-01-05Non-Destructive Testing of Rail for the introduction of other equipment.*

2 *Probe 4 is an alternative to Probe 3*

3 *The Probes specified are the minimum requirements for general testing of rail and welds. Other probes maybe used to target other areas or specific rail defects.*

70° Probe: *This probe is used to ultrasonically examine the railhead area for defects of a transverse nature only, including weld defects. All probing with a 70° probe should be done in both testing directions. 70° probes were originally chosen for use in uni-directional track where transverse defects (TDs) tend to occur at 18 - 22º. However with bi-directional track the TDs can be more vertical and do not always reflect the 70º*

38° Probe: *Probe 2 is actually 38° but sometimes referred to as '35° Probe'. Defects located by this probe include bolt hole cracks and defects of a transverse nature in the web and flange (section below the web only). All probing with a 38° probe should be done in both testing directions from the running surface of the rail.*

0° Probe: *This probe is used to ultrasonically examine the full rail depth. Defects located by this probe include bolt hole cracks and longitudinal defects of a vertical or horizontal nature in the head, web and flange (in the section below the web only).*

3.3 Couplant

For normal rail testing, water should be used as a couplant. This can be thickened with methyl-cellulose (e.g. wall paper paste) if necessary. A detergent (e.g. dish wash liquid or truck wash) can be added to the water as a wetting agent. In exceptional circumstances diesel may be used. Care should be taken to minimise the amount used.

Use oil as the couplant on calibration blocks.

4 Part B – Pre-Test Calibration and testing procedures

4.1 Calibration Process

Ultrasonic equipment shall be re-calibrated within the intervals specified in **Error! Reference source not found.** (Section *4.2*). Calibration should be carried out in accordance with the requirements of AS 2083 or as directed in this document.

4.2 Calibration periods

Table 2: Calibration Schedule for Ultrasonic Testing Equipment

INSTRUMENT FEATURES	RECORDING INTERVALS	DOCUMENTATION
Vertical linearity	12 monthly	ETG0103F-03
Horizontal linearity	12 monthly	ETG0103F-03
Probe shoe condition	Daily	Not Required
Angle beam probe index point	Daily	ETA0105F-01
Angle beam probe beam angle	Daily	ETA0105F-01
All probe gain reserve (OSG) >20dB,	12 monthly	ETG0103F-03
Calibration Blocks	2 Yearly	ETG0103F-04

4.3 Calibration Blocks

The following blocks are required for calibrating hand held ultrasonic equipment:

- V1 (No 1) Block from AS2083 (see *Attachment A*)
- V2 (No 5) Block from AS2083 may also be used for field calibration (see *Attachment B*)
- Rail Specific Gain Calibration Block (See Figure 1). This block is 250 x 75 x 25mm with a 1.5mm side-drilled hole (SDH) 50mm from the top surface and 50mm from one end.

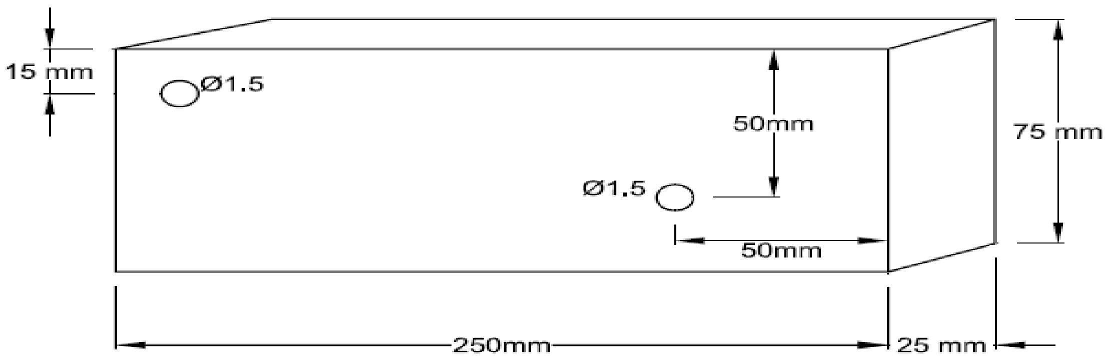


Figure 1 - Rail Specific Gain Calibration Block

Note: *New modified blocks now have an additional 1.5mm hole drilled across the block at a depth of 15mm.*

4.4 Calibration Settings

Probes shall be calibrated for range and sensitivity as shown in Table 3.

Table 3: Probe Calibration Settings

PROBE	ANGLE	FREQUENCY	RANGE CALIBRATION	SENSITIVITY CALIBRATION
Probe 1 Single 70°	70°	2MHz	0-200mm for most Rail tests 0-250 for 60kg rail.	80% FSH from a 1.5mm SDH @ 25mm depth, plus 6dB for scanning
Probe 2 38°	38°	2MHz	0-250mm	80% FSH from a 1.5mm SDH @ 50mm depth, plus 6dB for scanning
Probe 3 Single 0°	0°	2MHz	0-200mm	80% FSH from a 1.5mm SDH @ 50mm depth, plus 6dB for scanning
Probe 4 Twin 0°	0°	2MHz	0-200mm	80% FSH from a 1.5mm SDH @ 50mm depth, plus 6dB for scanning
Probe 5 Small 0°	0°	4MHz miniature	0-100mm	80% FSH from a 1.5mm SDH @ 50mm depth, plus 6dB for scanning
Probe 6 Single 70°	70°	4-5MHz	0-100mm	80% FSH from a 1.5mm SDH @ 15mm depth of V1 block, plus 6dB for scanning
Alternative Probe 6 Twin 70°	70°	4-5MHz twin	0-100mm	80% FSH from a 1.5mm SDH @ 25mm depth, plus 6dB for scanning

Note: FSH = Full Screen Height SDH = Side Drilled Hole

4.5 Pre-Test checks

4.5.1 Inspection of Probe Shoe (Check: Before use) Record: Weekly

Check the probe shoe for uneven wear. If the shoe is worn to within 0.5mm of the probe case, replace the shoe. If the shoe is worn such that the angle is outside ±2° of the nominated angle, flatten and correct the angle of the shoe with fine emery cloth or wet and dry paper before continuing. Probes will become concave through use; concavity consistent with the rail profile is acceptable.

4.5.2 Recordable pre-test check of Probe Index (Before use)

Peak the signal from the 100mm radius surface of the V1 Calibration Block shown in Figure 2. When the signal is maximised, the probe index point will correspond to the 0.5mm slot in the block. Mark this index point on the probe and record it on ETA0105F-01 Record and Report of Ultrasonic Test (see example in Attachment A), as the measured distance from the front of the probe.

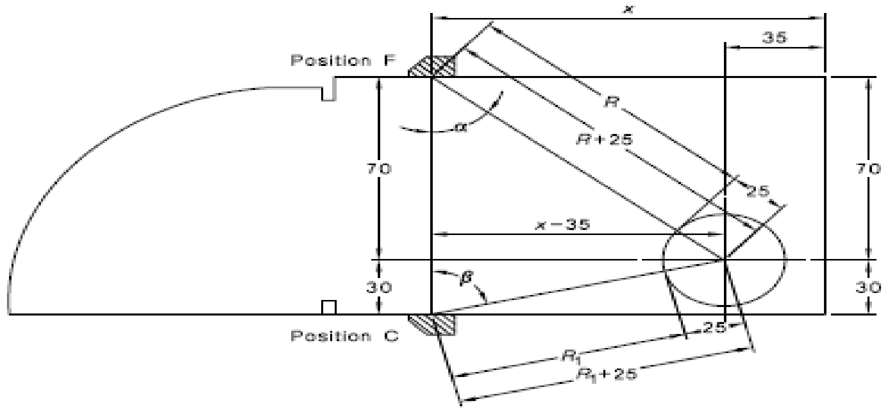


Figure 2 - Geometric Determination of Beam Angle Using Calibration Block No. 1 (From AS 2083) Refer to Attachment A for full details of the Calibration blocks.

4.5.3 Calibration of Beam Angle (Weekly or before use)

Measure the beam angle using AS 2083 No 1 block. Place the probe at either position “C” or “F”, pointing towards the 50mm diameter hole. Identify where the probe index lines up with the engravings on the block and record the indicated angle. Correct the angle by linishing (or fine sanding) the shoe until the angle is within the ±2° limit.

Notes: *After linishing (or fine sanding) the index point will have changed. Find the “new” index point before measuring the “new” beam angle.*

Since the velocity of ultrasonic waves is temperature dependent, beam angle determinations should be made at a temperature similar to that which pertains to the working environment.

For a probe with a Perspex shoe transferred from a surface cool to the touch (e.g. 10°C) to one warm to the touch (e.g. 40°C), there would be a reduction in velocity of the order of 3.5% which in turn would result in an increase of beam angle of the order of 2 degrees for a 45º probe and 6 degrees for a 70º degree probe (for further details see AS 2083).

4.5.4 Recording of Overall Systems Gain (OSG) (12 Monthly or New Probe)

The gain reserve is the remaining gain that will achieve full screen height (FSH). With the instrument calibrated for the required task, check that there is at least 20dB gain in reserve. If OSG is < 20dB, replace probe.

4.6 Evaluate Dead Zone (Weekly or before use)

The dead zone is the area on the screen of an ultrasonic flaw detector, after the initial pulse. At this point, accurate resolution of the reflector from internal defects is not possible. This is due to noise interfering with the interpretation. All single crystal probes have a dead zone. The dead zone normally equates to the top 4 to 8mm of the rail (See Table 5, Test 1).

Check for the dead zone appearing on the flaw detector during the rail test. Ensure that it doesn’t interfere with interpretation of results where critical defects may lie.

When using Probe No 1 (single crystal 70°) to test for railhead defects, the dead zone will need constant evaluation. If the dead zone is greater than the first 30mm of the beam path length, it is possible for defects that lie in the top 10mm of the railhead to be missed. In such cases the alternative high frequency twin crystal 70° probe can be used.

4.7 Sensitivity (Weekly or before use)

Sensitivity is the ultrasonic equipment's capacity to detect a small discontinuity. The sensitivity is determined by the amplification (or gain) required to display a reference reflector of known size at a pre determined screen height.

For rail testing the sensitivity is set for the required scan using the 1.5mm side drilled hole from either the Rail Specific or V1 Calibration Blocks. The block and position used (50mm, 25mm or 15mm), depends on the probe angle. These are listed in **Error! Reference source not found.**. There are two levels of sensitivity used:

- **Evaluation Sensitivity –** Adjust the height of the reflection from the 1.5mm side drilled hole, for 80% screen height at the depth defined in **Error! Reference source not found.**. NB: At this level of gain setting all defect reflectors that reach or exceed 40% screen height must be evaluated for size and type, and recorded.
- **Scanning Sensitivity** - For scanning add 6dB to the evaluation gain setting. Once a defect is detected the 6dB must be removed to evaluate and size the defect.

4.7.1 Notes on Sensitivity Testing

4.7.1.1 Temperature Effects on Sensitivity

The temperature of the rail will have an effect on the ultrasonic signal. An increase in the rail temperature will reduce the signal amplitude. This will change both the beam angle and reflectivity from defects.

If the temperature of the rail exceeds 50°C, record the temperature on the report form and check all calibrations.

4.7.1.2 Use of other Probe angles

Sometimes the nature, size or shape of a defect will require different probe angles to be used to determine the defect's greatest reflectivity. In this case, use the most appropriate probe angle to determine the true size of the defect. It may also be necessary to increase the evaluation gain by 6 or 12dB to compensate for misaligned defects (refer to AS 2207 Para 3.1).

4.7.1.3 Alternative Methods

Alternative methods for testing the head, web and foot may be used to further evaluate indications. Some examples of alternative methods include:

- Use of two 45°, 2MHz probes as either "pitch and catch" technique or "through transmission".
- Use of the 38° search unit to monitor the rail base echo as the sound is passed through the weld when the probe is passed over the weld. Any significant interface within the weld will reflect the sound away from the rail base and the returning base signal will be lost. This is a type of "through transmission" test, using only a single search unit.

4.7.2 Suppression

No suppression is to be used during any ultrasonic rail testing.

5 Manual Test Procedures

5.1 General Testing Procedure

5.1.1 Pre-Test Checks

Before starting any test, check the integrity of:

- All cables and connectors
- The condition of all probes (i.e. faces, sockets)

5.1.2 Visual Inspection

Before any ultrasonic testing is carried out, the area to be tested shall be thoroughly visually inspected. Typical abnormalities that may indicate the presence of internal defects include:

- Rail surface condition including wheel burns, squats, ‘bruises’, cracking
- Depression in Railhead (i.e. a dark streak on the running surface, indicating sagging of the railhead.)
- Widening (bulging) of the railhead, and the contact band
- Cracking or distortion in the upper fillet area.
- Porosity in any welds or weld repair sections.
- Rolling Contact Fatigue (RCF), indicated by spalling, gauge corner cracking, head checking etc.
- Rust Marks or ‘bleeding’ in the head/web fillet region, which occurs when the crack nears the rail surface
- On straight track the measurement of the head width, **at the gauge point**, may also be used to indicate the possible presence of Vertical Split Head (VSH) defects
- All substandard visual conditions should be reported immediately as a track fault. *Attachment B* shows ETA0105F-02 Rail Flaw Report as an example of a reporting form for Visual Inspection Defects.

5.1.3 Localised Ultrasonic Testing Procedure

- Locate area of defect indications as sprayed or marked on rail from manual or visual inspection, or as indicated on work job sheet.
- Locate all other defect indications and areas of loss of bottom or inconclusive tests. Scanning aids (e.g. “the pogo stick”) may be used.
- Evaluate the Dead Zone (see Section 4.6).
- All indications that exceed 40% of FSH at evaluation sensitivity shall be evaluated for type and size.
- **Constantly take note of the positive indications of normal test procedure** e.g, continuous back wall echo, grain structure, heat affected zone etc. Investigate the cause if any of these positive indications are not evident.
- Classify and size defect as per Section 6.

5.1.4 Reporting Test Results

All defects found and all weld tests carried out should be reported as per Section 7 Recording and Reporting Requirements for Rails and Welds.

5.2 Typical Scanning Positions

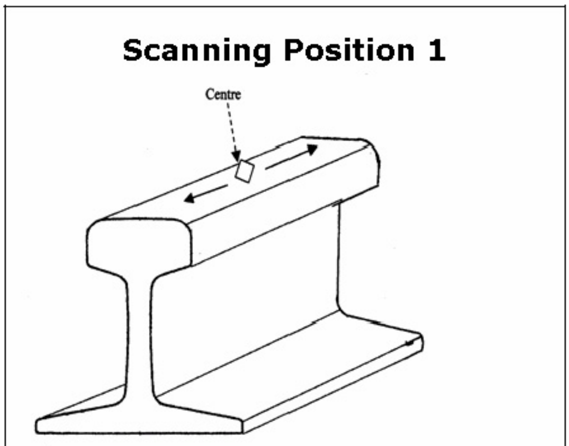


Figure 3.a Scanning from the centre of the head over the web

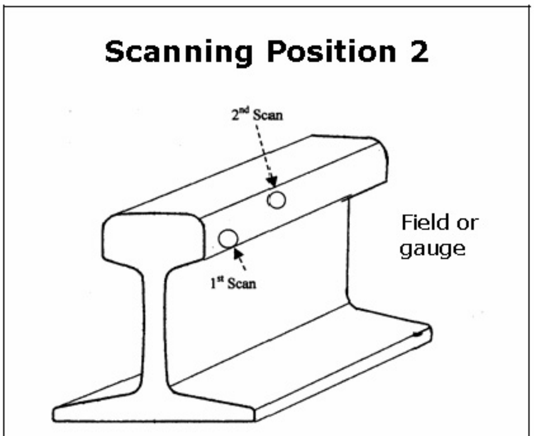


Figure 3.b Scanning from the side of the head

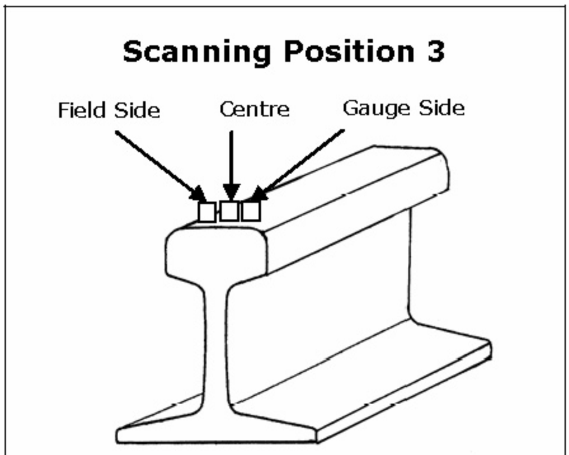


Figure 3.c Scanning the head over field, centre or gauge side

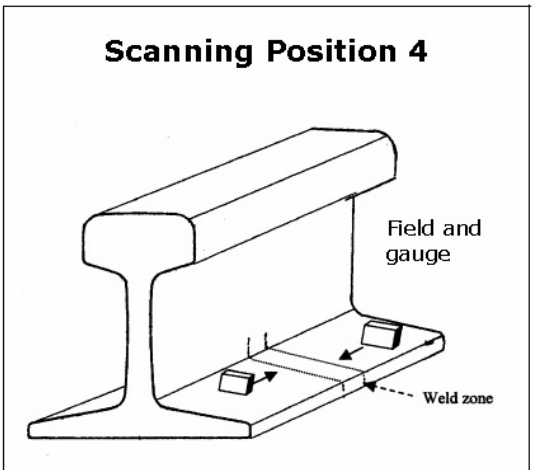


Figure 3.d Scanning the foot of the weld.

Figure 3 - Typical scanning positions

Table 4: Probe that can be used in each scanning position

RAIL TESTING		SCANNING POSITIONS			
Probes	Angle (◦)	1	2	3	4
1	70	☑		☑	
2	38	☑			
3	0	☑	☑	☑	
4	0	☑	☑	☑	
5	0		☑		
6	70				☑

5.3 General Long Length Test Procedure of Rails

Carry out Pre-Test Checks (Section 5.1.1)

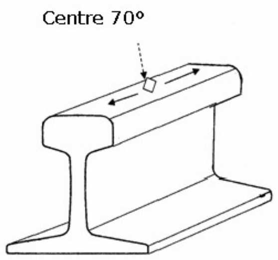
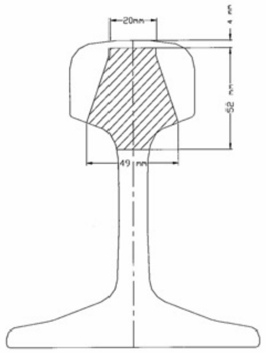
Inspect the rail for visual signs of defects (see Section 5.1.2) before the length is ultrasonically tested.

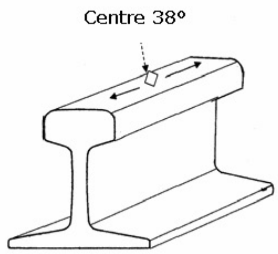
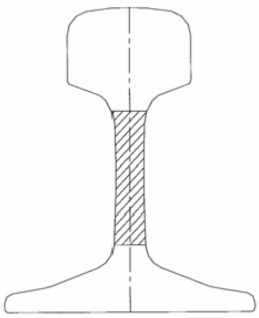
Use a trolley (or if none is available “the pogo stick”) and test the length of the track using the probes and probe positions described in **Error! Reference source not found.**5

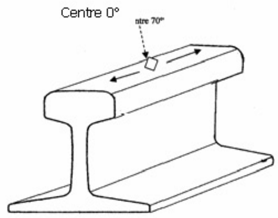
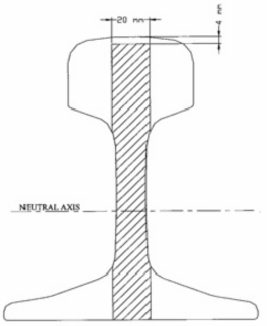
Locate all defect indications and areas of loss of bottom. Where indications are detected, clearly mark the rail.

Carry out detailed inspection of the indications found, following the procedure in 5.4 Testing of Indications in Rails, 5.5 Non-Destructive Examination of Welds or 5.6 Manual Ultrasonic Examination of Railhead Repair Welds as appropriate.

Table 5: Ultrasonic Examination of General Lengths

TEST 1: Scanning Position 1	**Area Covered by Test**	**Probe 1: 70° Probe**
		This probe examines the railhead area and the top section of the web for defects. All scanning shall be done in both testing directions. Scanning shall be carried out nominally over the centre line. If there is evidence of RCF, initial inspection should be done as close as possible to the RCF for underlying transverse defects (TDs). Where possible, try scanning with the probe angled under the RCF. If there are rolling indications from the web area check the web for vertical split web with a miniature 0° probe. Refer to Appendix A for readings obtained when TDs are present.

TEST 2: Scanning Position 1		**Probe 2: 38° Probe**
		Defects located by this probe include bolthole cracks and defects in the web and foot. All probing with a 38° probe shall be done in both testing directions. Refer to Appendix B for readings obtained when bolthole cracks are present.

TEST 3: Scanning Position 1		**Probe 4 (Can use Probe 3): 0° Probe**
		This probe examines the full rail depth, including welds. Defects located by this probe include bolthole cracks and longitudinal defects of a horizontal nature in the head, web and foot. Defects of a vertical nature may be indicated by a loss of back wall echo (BWE). Refer to Appendix C for readings obtained when defects are present.

5.4 Testing of Indications in Rails

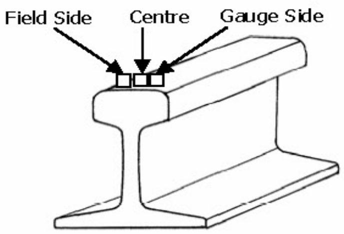
Carry out Pre-Test Checks (Section 5.1.1)

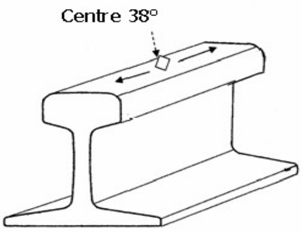
Inspect the rail for visual signs of defects (see Section 5.1.2) before the length is ultrasonically tested using scanning positions described in Table 6.

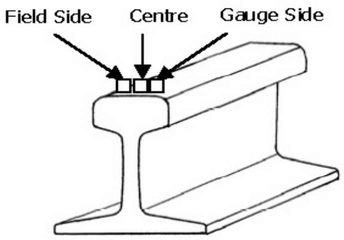
Carry out the Localised Ultrasonic Testing Procedure as described in Section 5.1.3

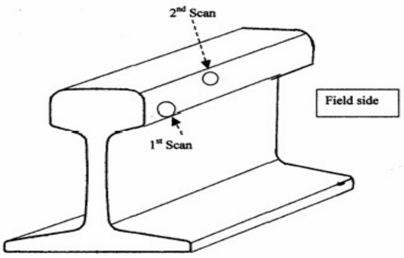
Report test results (Section 5.1.4)

Table 6: Localised Ultrasonic Examination of Rails – Defect Sizing

TEST 1: Scanning Position 3	**Probe 1: 70° Probe**
 Three scans shall be carried out, gauge side, centre and field side.	This probe examines the railhead area and the top section of the web for defects. All scanning shall be done in both testing directions. Scanning shall be carried out over the centre line and then over field and gauge sides. If there are rolling indications from the web area check the web for vertical split web with a miniature 0° probe.

TEST 2: Scanning Position 1	**Probe 2: 38° Probe**
	Defects located by this probe include bolthole cracks and defects in the web and foot. All probing with a 38° probe shall be done in both testing directions.

TEST 3: Scanning Position 3	**Probe 4 (Can use Probe 3): 0° Probe**
	This probe examines the full rail area, including any welds. Defects located by this probe include bolthole cracks and longitudinal defects of a vertical or horizontal nature in the head, web and foot.

TEST 4: Scanning Position 2	**Probe 5, Miniature 0º Probe**
	Scanning for Vertical Split Head (VSH) and inclusion band (IB) defects is done by making two scans along the vertical face of the field side of the head. The first scan is conducted adjacent to the base of the head and the second scan adjacent to the top of the head. If a VSH is indicated, visually check the under head radius for cracking, discolouration or bulging.

5.5 Non-Destructive Examination of Welds

This section describes the procedure for the Non-Destructively (visual, geometric and manual ultrasonic) examination of welds in rail lines, including Aluminothermic, Wire Feed (Fluxcore) and Flashbutts. All new welds must be Non-Destructively tested within the timeframes specified in per ETA-01-05 Non-Destructive Testing of Rail (for Internal & Surface Defects) Part 3.1

5.5.1 General Testing Procedure and Visual Inspection of Weld

Carry out Pre-Test Checks (Section 5.1.1)

Inspect the rail for visual signs of defects (see Section 5.1.2) before the length is ultrasonically tested. The entire weld shall be inspected including the ground weld surface, the heat-affected zone on both side of the weld.

Identify, record and report evidence (including size and position) of the following:

- Cracks
- Tears
- Gouges
- Gas porosity
- Shrinkage porosity
- Slag or sand inclusions
- Underfill
- Weld shape and contour (Vee or Y shape)
- Fins
- Electrode burns
- Grinding burns
- Hammer marks
- Abnormal heat affected zone (HAZ) indications
- Riser break indicators (porosity, gas holes etc)
- Bolt hole distance (bolt holes must be greater than 65mm from weld)

The maximum dimension of any pores, slag inclusions, sand inclusions or metal beads shall be measured as follows and the number for the head, web and foot recorded:

- Group in size bands:
  - Small (>0mm to 1mm)
  - Medium (>1mm to 2mm)
  - Large (>2mm to 3mm)
- Where multiple imperfections are revealed, they shall be counted and measured as a single imperfection if they are less than 1mm apart. Areas containing micro-porosity or inter-dendritic shrinkage (hot tear) are not counted as single imperfections and therefore reported separately.

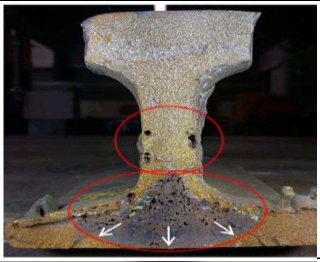
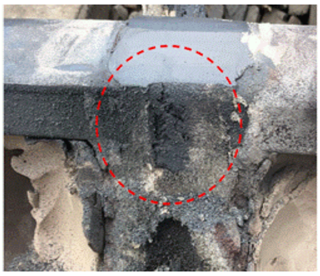
Table 7 and Table 8 provides guidance for visual assessment of welds

Table 7: Visual Guide on Weld Appearance and Responses

GRADE	INTERPRETATION	EXAMPLE	ACTION
1	Compliant		No Action
2	Non-Compliant but acceptable		Clean and reinspect. If appears poor, record it as a known condition. P3
3	Marginally acceptable		Clean and reinspect. If appears poor, record it as a known condition. P2
4	Unacceptable		Record as Known Condition weld to be cleaned. P1 NDT testing is to be performed once the weld is cleaned.

Table 8: Visual Guide on Weld Faults and Response

WELD FAULT	INTERPRETATION	EXAMPLE	ACTION
1	Lack Of Fusion		E = Install bow-lock plate. P1 = Replace weld.

WELD FAULT	INTERPRETATION	EXAMPLE	ACTION
2	Porosity		E = Install bow-lock plate. P1 = Replace weld.
3	Inclusion		E = Install bow-lock plate P1 = Replace weld
4	Out of Squareness > 2mm		Non-Compliant, P2 = Weld to be replaced.
5	Weld Tear		E = Install bow-lock plate. P1 = Replace weld.
6	Black Holes		E = Install bow-lock plate. P1 = Replace weld.
7	Sand Burns		E = Install bow-lock plate. P1 = Replace weld.

5.5.2 Geometric Inspection of Welds

The ultrasonic inspector is required to check Weld Geometry as per ETS-01-00 Section 1: Rail. The recording requirements are detailed in Section 7 Recording and Reporting Requirements for Rails and Welds. The technical specifications are summarized in table 9.

Table 9: Tolerances of finished rail welds (from ETS-01-00)

FACTOR	REQUIREMENT
Peak in running surface (over 1 metre)	up to 0.3mm preferred, maximum 0.5mm
Dip in running surface (over 1 metre)	Strictly no dip allowed
Vertical deviation in rail running surface (Change in weld ramp angle)	7 milliradians over 50 mm base
Gauge widening (over 1 metre)	0.5 mm max (Less preferred) at gauge point.
Gauge narrowing (over 1 metre)	0.5 mm max (Less preferred) at gauge point.

All substandard geometry should be reported immediately as a track fault. ETA0105F-02 Rail Flaw Report as an example of a reporting form for Geometric Inspection Defects.

5.5.2.1 Ramp Angle

The top surface must also be checked with a P1 (dipped weld) gauge or an approved measuring system capable of measuring ramp angles. The maximum ramp angles at the top of the rail shall be checked for a distance of 500mm either side of the weld. The maximum ramp angles on both sides shall be recorded in milliradians.

If the ramp angle is satisfactory it need only be signed off on the weld return form. If a defect is located or there is no weld return form, measurements shall be recorded as per section 5.5.5.

5.5.2.2 Surface Alignment (Top and Alignment)

Top surface alignment measurements should be taken with an ARTC finishing straight edge and metric taper gauge, feeler gauge or electronic measuring system as described in Figure 4 and Figure 5. A modified straight edge with 0.5mm “nibs” can be used to measure peak. Lateral alignment should be measured as in Figure 6. If the weld alignment is satisfactory it need only be signed off on the weld return form. If a defect is located or there is no weld return form, measurements shall be recorded as per Section 5.5.5.

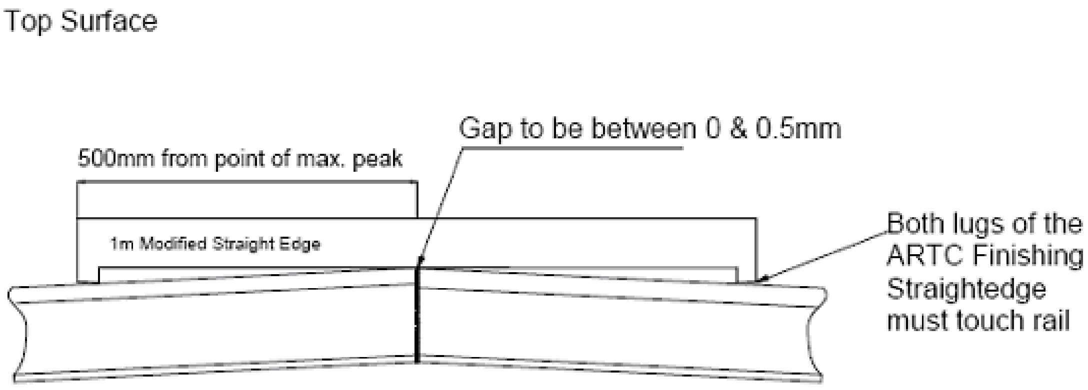


Figure 4 - Weld misalignment tolerance in vertical plane (peaking). Maximum peak allowed in 1m is 0.5 mm.

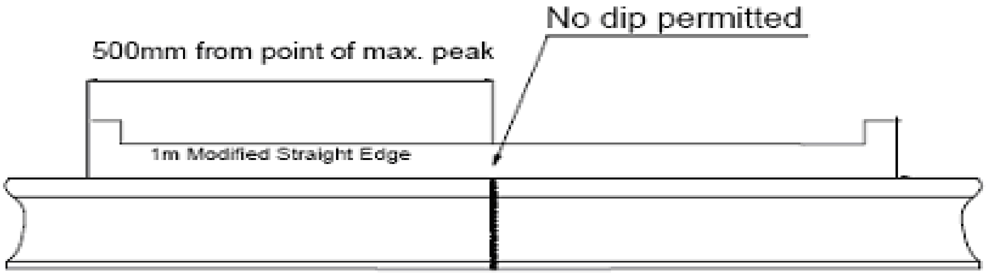


Figure 5 - Weld misalignment tolerance in vertical plane (dip). No dip permitted.

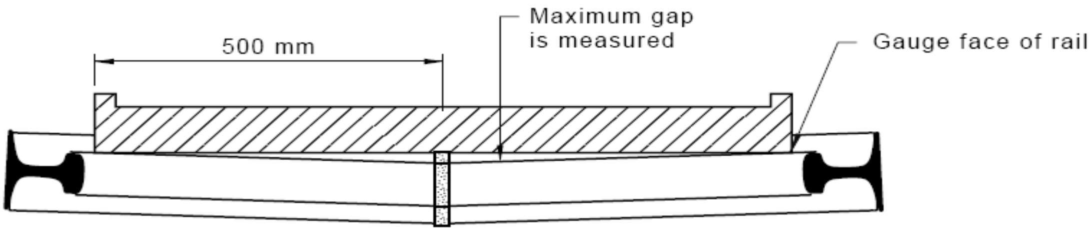


Figure 6 - Joint Geometry - Surface Alignment Method - Lateral (For Straight Track)

The recorded value is the measured gap. This should be no more than 0.5mm.

Note: For curved track the gap is not covered in this Standard.

5.5.3 Ultrasonic Inspection of the Weld

Carry out the Localised Ultrasonic Testing Procedure as described in Section 5.1.3 using the probes described in Table 8.

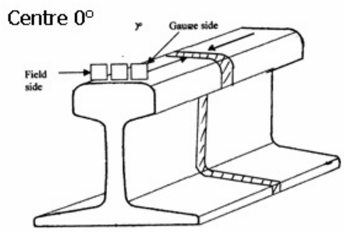
5.5.4 Inspection of Punch Marks

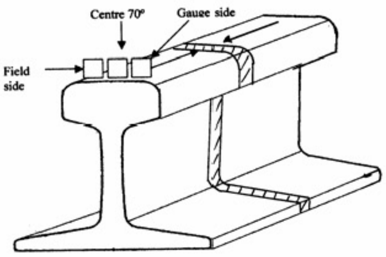
The ultrasonic inspector is required to find the punch marks on the rail. A measurement is to be taken of the length between punch marks and recorded on the Welders' Return Form.

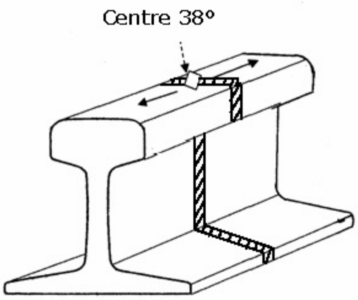
5.5.5 Reporting Test Results

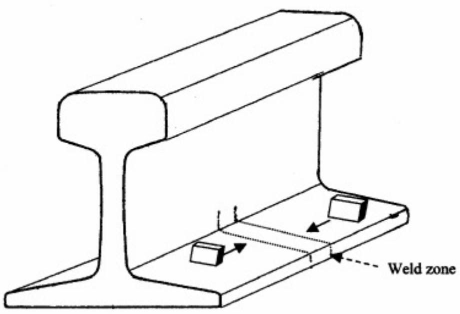
Report test results (Section 5.1.4)

Table 10: Manual Ultrasonic Examination of Welds

TEST 1: Scanning Position 3	**Probe 4 (Can use Probe 3): 0° Probe**
 Three scans shall be carried out, gauge side, centre and field side.	Scan over the weld and at least 150mm either side of the weld, being careful that any indications coming from the under-head radius of the web are correctly interpreted. Examines the full rail weld and Heat Affected Zone (HAZ) area and locates defects in the head, web or foot; including Head Web separation, weld porosity and shrinkage.

TEST 2: Scanning Position 3	**Probe 1: 70° Probe**
 Three scans shall be carried out, gauge side, centre and field side in both testing directions.	Examines: railhead weld area and the top section of the web for defects. The scanning distance will be sufficient to scan over the weld on at least 250mm on both side of the weld. If shallow defects are detected that run into the dead zone of the ultrasonic trace then an additional scan with Probe 6 (70° single or twin crystal) shall be used.

TEST 3: Scanning Position 1	**Probe 2: 38° Probe**
	Locates defects in the web and foot. All probing with a 38° probe shall be done in both testing directions Scanning shall cover from the head to the foot of the weld, ensuring that a signal appears from the foot of the rail and weld. Use this foot signal to confirm that the system is working.

TEST 4: Scanning Position 4	**Probe 6: 70° Probe Single or twin crystal**
	This probe is used to detect weld defects in the foot of the rail. A scraper and wire brush should be used to improve the surface condition before testing commences. Scan from the weld toe back to approximately 100mm and ensure full weld coverage on all four foot faces adjacent to the weld. Measure defect as a length across the rail (parallel to the weld).

5.6 Manual Ultrasonic Examination of Railhead Repair Welds

This section describes the procedure for the manual ultrasonic examination of railhead repair welds. Repair weld processes may include Aluminothermic, Wire Feed (Fluxcore) or SMAW (manual stick welding).

5.6.1 General Testing Procedure

Carry out Pre-Test Checks (Section 5.1.1)

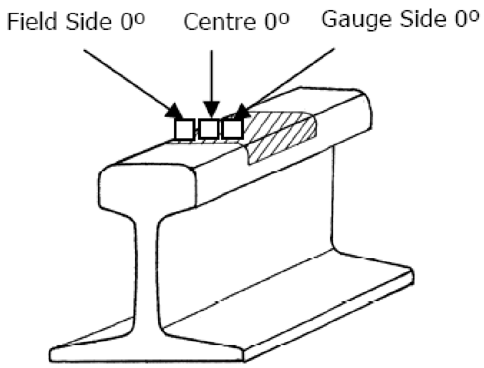
Inspect the rail for visual signs of defects (see *Section* 5.1.2) before the length is ultrasonically tested. Check for abnormalities that may indicate the presence of internal weld defects such as:

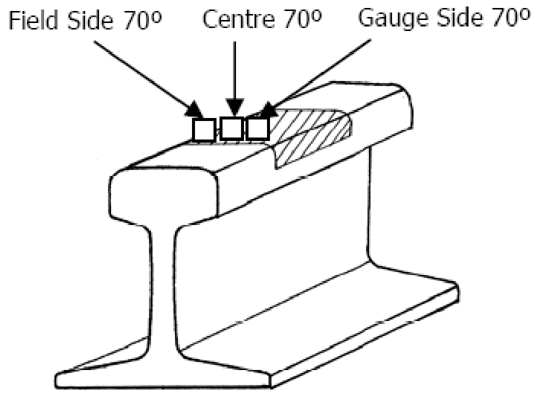
- Porosity
- Slag inclusion
- Hot tears (inter-dendritic cracking)
- Lack of fusion/cracking

Carry out the Localised Ultrasonic Testing Procedure as described in Section 5.1.3 using the probes described in Table 9.

Report test results (Section 5.1.4)

Table 11: Manual Ultrasonic Examination of Railhead Repair

TEST 1: SCANNING POSITION 3	PROBE 4 (CAN USE PROBE 3): 0˚PROBE
	Examines the full rail weld area. Defects located by this probe include weld porosity, lack of fusion and shrinkage. For SAMW or Wire Feed Welding slag inclusions and other associated welding defects may be detected.

Test 2: Scanning Position 3	Probe 6: Twin 70˚ Probe
 **Three scans shall be carried out, gauge side, centre and field side**	Examines: railhead weld area. Three scans shall be carried out, gauge side, centre and field side in both testing directions. Scanning shall include the entire weld length and extend a further 150mm past the HAZ.

5.7 Test Procedure of Turnouts Switches and Crossings

This section sets out the requirements and process to be used for the manual testing of turnouts, including crossings and switches, for internal defects.

5.7.1 General Testing Procedure

Carry out Pre-Test Checks (Section 5.1.1)

Inspect the rail for visual signs of defects (Section 5.1.2) before the length is ultrasonically tested. Also check for:

- Switch blades – Chipping.
- Nose - Spalling, flattening.
- Wing rail – Gouging, flattening, chipping

The majority of the turnout is normally inspected by the Continuous Ultrasonic Testing Car. However, due to the rail shape near the nose, wing rail and in the switch blades it is difficult to achieve acoustic coupling. Therefore except the stock rail, manual tests may be required on the rails and track components. This may include switch rails, stock rails, nose and wing rails. This usually includes the full switch assembly (stock rail and blade), crossing (both wing and point rails) and all other bolt hole and aluminothermic weld areas throughout the turnout.

Carry out the Localised Ultrasonic Testing Procedure as described in Section 5.1.3 using the probes described in Table 10 and 10a.

5.7.2 Dye Penetrant Testing of Switch Blades

Switch tips can be tested using Dye Penetrant testing. The following procedure should be used when Dye Penetrant testing is used:

5.7.2.1 Surface Cleaning

Clean the surface with a scraper/brush/rag to remove all grease/heavy rust/dirt etc. Finish the cleaning with a spray solvent. Allow solvent to dry off.

Cleaning should be carried out on the gauge face of the switch blade from the point end of the switch blade back at least 750mm and from the top of the blade to a depth of 70mm.

Note: Attachments to the side of the switch will set some limit to the depth of the area that can be tested.

5.7.2.2 Apply the Dye Penetrant

Spray Dye Penetrant onto the test area from the point of the blade, back at least 750mm and to a depth 70mm from the top of the blade. Leave the dye on the switch blade for a dwell time of 20 minutes. Trains running over the blade during this time will assist the test and are not a problem. Clean the surface of the test area to remove all residual dye. This is done by spraying the solvent onto a piece of rag and thoroughly wiping all dye from the surface. Do not spray solvent directly on to the test area.

5.7.2.3 Apply the Developer

Spray developer on to the blade to cover the full test area.

5.7.2.4 Check for Defect Indications

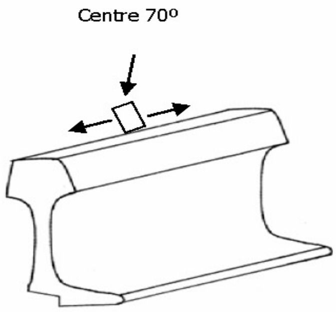
Allow 3 to 5 minutes for any indications to develop. If any cracks are present in the test area of the switch blade, the cracks will appear as a distinct red line. If any crack is found in the switch blade it should be reported for evaluation. The risk of a rail break increases with the crack's proximity to the tip of the switch.

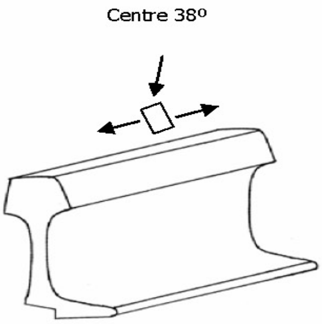
5.7.3 Reporting Test Results

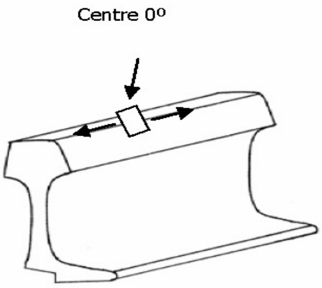
Report test results (Section 5.1.4).

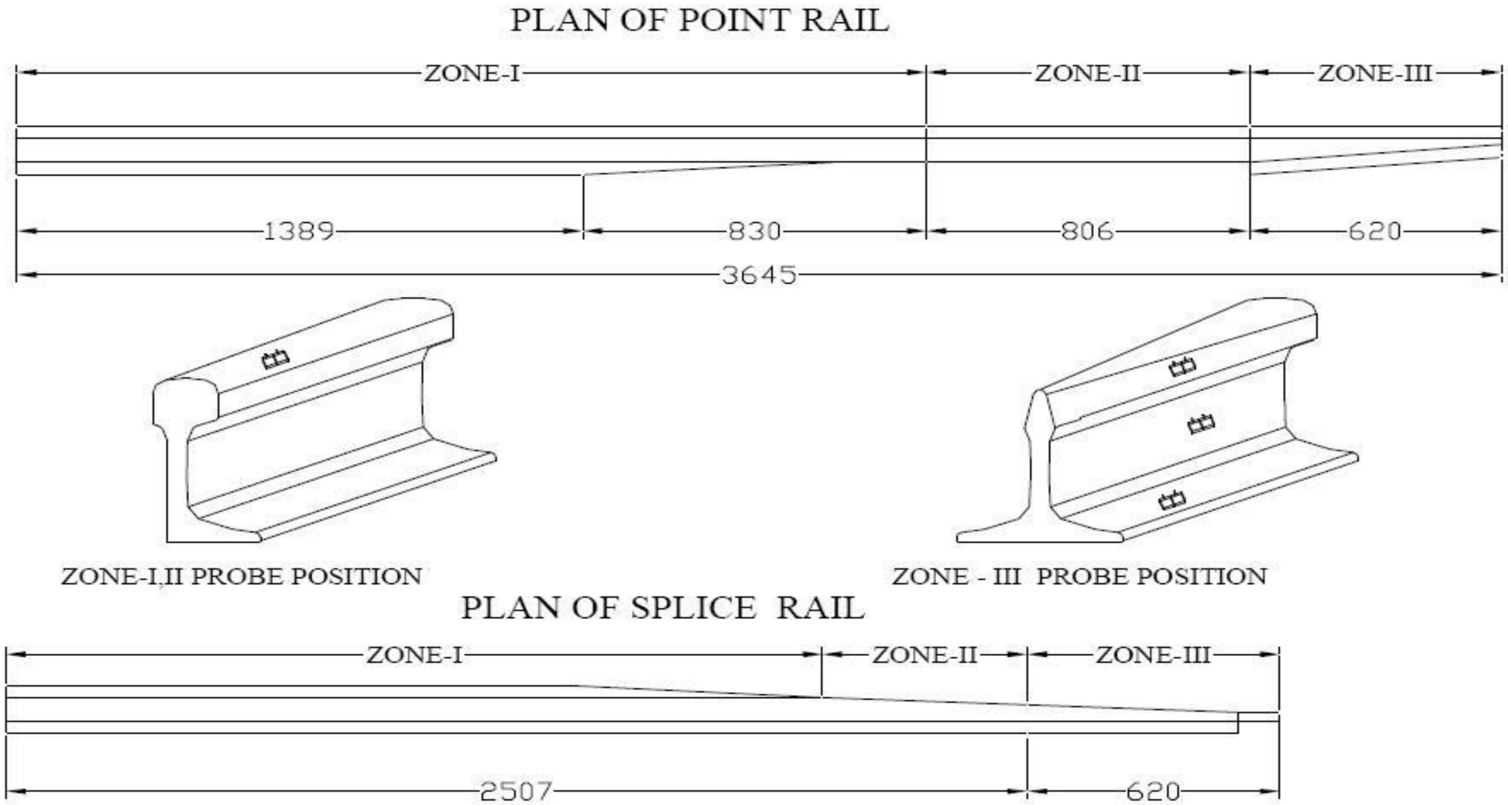
In NSW, switch blade defects found should be reported on AMT-FM-004 Inspection/Defects Found Report Form from AMT-PR-010 Enterprise Asset Management System.

Table 11: Manual Ultrasonic Turnouts, Switch and Crossings

TEST 1: Scanning Position 1	**Probe 1: 70° Probe**
	This probe examines the railhead area and the top section of the web for defects. All scanning shall be done in both testing directions. Scanning shall be carried out nominally over the centre line. If there is evidence of rolling contact fatigue, initial inspection should be done as close as possible to the rolling contact fatigue for underlying TDs. If there are rolling indications from the web area check the web for vertical split web with a miniature 0º probe.

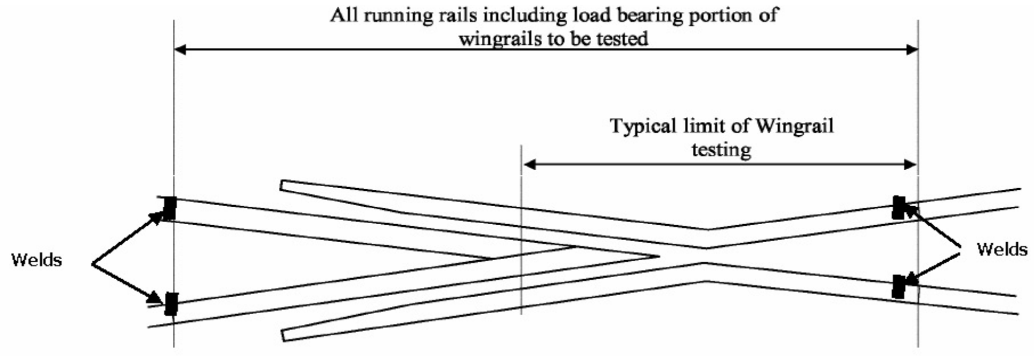
TEST 2: Scanning Position 1	**Probe 2: 38° Probe**
	Defects located by this probe include bolthole cracks and defects in the web and foot. All probing with a 38° probe shall be done in both directions.

TEST 3: Scanning Position 1	**Probe 4 (Can use Probe 3): 0° Probe**
	This probe examines the full rail depth, including welds. Defects located by this probe include bolthole cracks and longitudinal defects of a vertical or horizontal nature in the head, web or foot.



TESTING PROCEDURE FOR POINT AND SPLICE RAILS FOR
1 IN 12 CROSSING B G 52 Kg

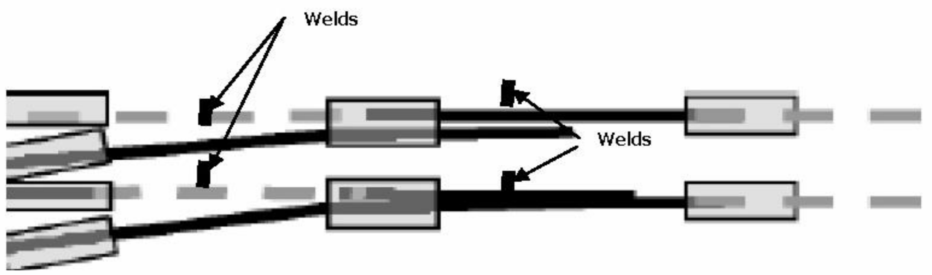
NOTE:- ALL DIMENSIONS ARE IN MILLIMETERS.



Note: *Testing of the crossing to include:*

- *From the nose to the first weld in each direction. Special attention should be given to the spliced area.*
- *The Wing rails from the splice to the first welds. (see previous note)*

Figure 8 - Crossing and wing rail testing



Note: *Testing of the Switch to include:*

- *From the first weld in front of the stock rails to the Heel.*
- *From the switch blade tips to the heel block or the first weld of a "fixed heel"*
  (Note: Some switches have heel blocks and some have "fixed heel" i.e. welded which will be the "first welds")

Figure 9 - Switch and stock rails

6 Classifying and Sizing Defects

All rail defects should be classified in accordance with ETS-01-00 Section 1: Rail.

6.1 Naming System of Defects (Nomenclature)

Defects which can be identified using non-destructive testing are illustrated in Figure 10.

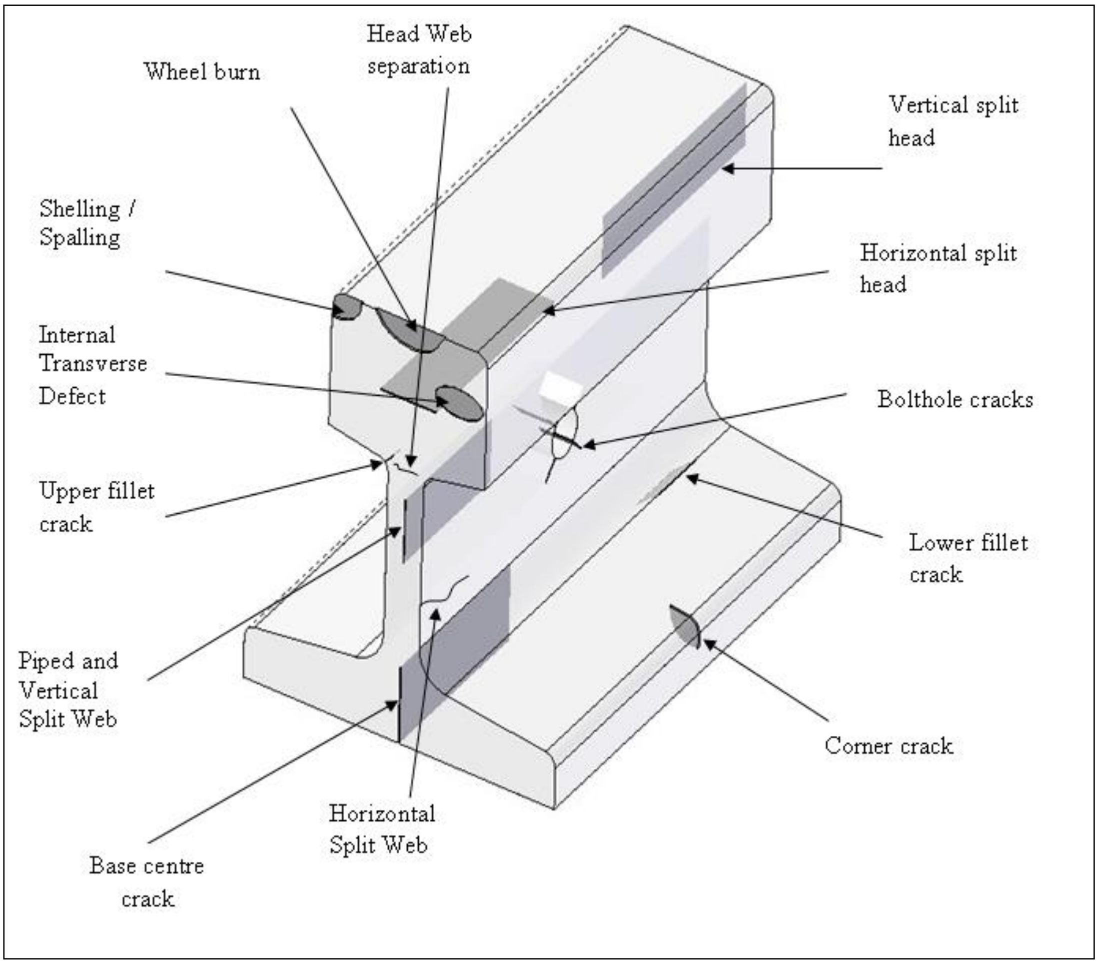


Figure 10 - Internal rail defects definitions

6.2 Measurements Required to Size effects

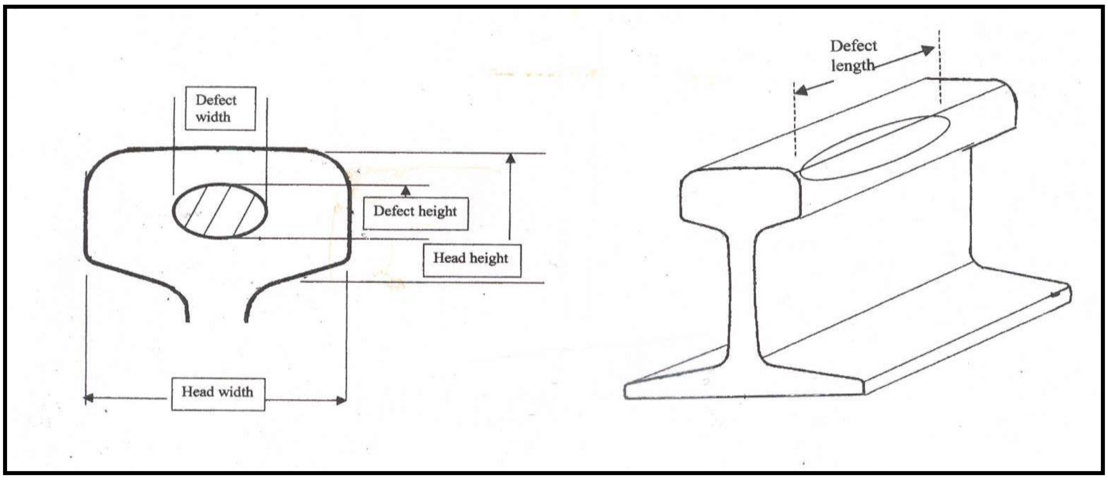


Figure 11 - Definition of defect dimensions

All indications exceeding 40% of full screen height at evaluation sensitivity shall be evaluated for size. Sizing should be done by the last significant echo method.

Table 12: Defect measurement reporting requirements

Internal Defect Type	Measure and Record			Method of Reporting Defect Size
	Width / probe travel	**Height**	**Length / probe travel**	**Small Medium or Large**
Head Defects				
Transverse Defect	✓	✓		✓
Wheel Burn	✓	✓		✓
Tache Oval	✓	✓		✓
Transverse Defect from Shelling	✓	✓		✓
Splits/cracks				
Horizontal Split Head			✓	✓ **E****
Vertical Split Head		✓	✓	✓ **+ IB* + E****
Horizontal Split Web			✓	✓
Vertical Split Web and piped rail		✓	✓	✓
Head and Web Separation			✓	✓
Foot and Web Separation			✓	✓
Bolt Hole Crack			✓	✓
Base Centre Crack				✓
Defective Weld				
Thermit Welds	As per rail defects			
Flashbutt Welds				

Note: **IB = Inclusion Band*
***E = Collapse of Railhead*

6.3 Sizing Defects using Angle beam (38° & 70°) probes

6.3.1 Height of Defect

Size for height using the “last significant echo” method.

Measure the probe travel length and record it. The graphs below are then used to calculate the defect vertical height. All distances are in millimetres.

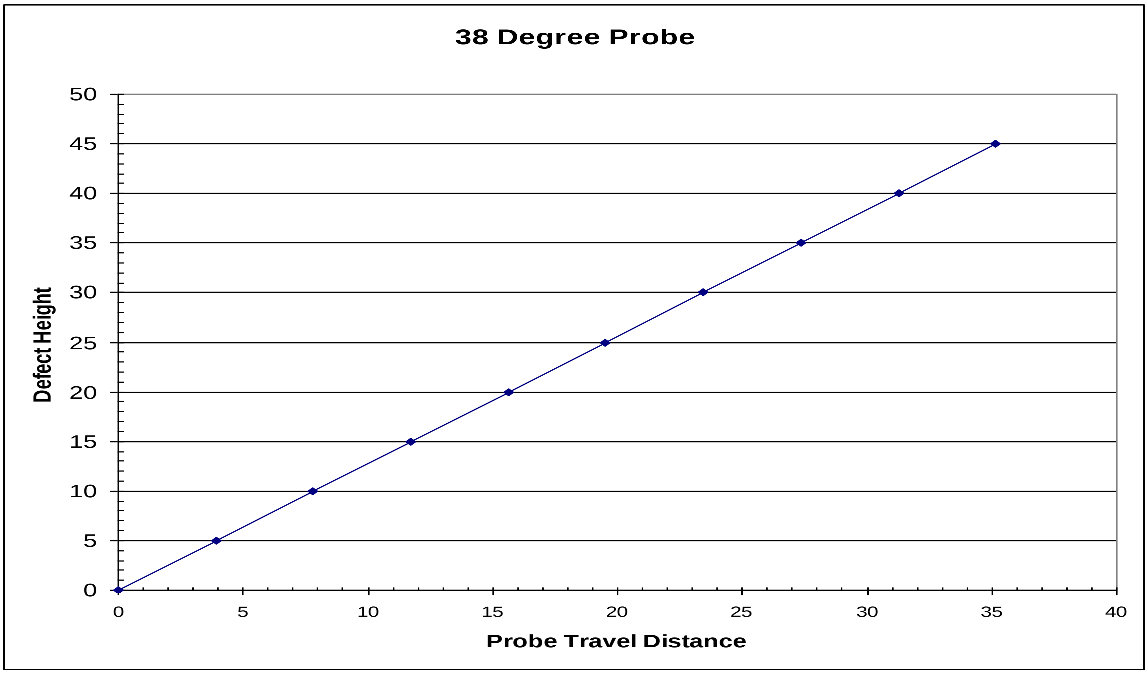


Figure 12 - Sizing defects using 38°♂ probe

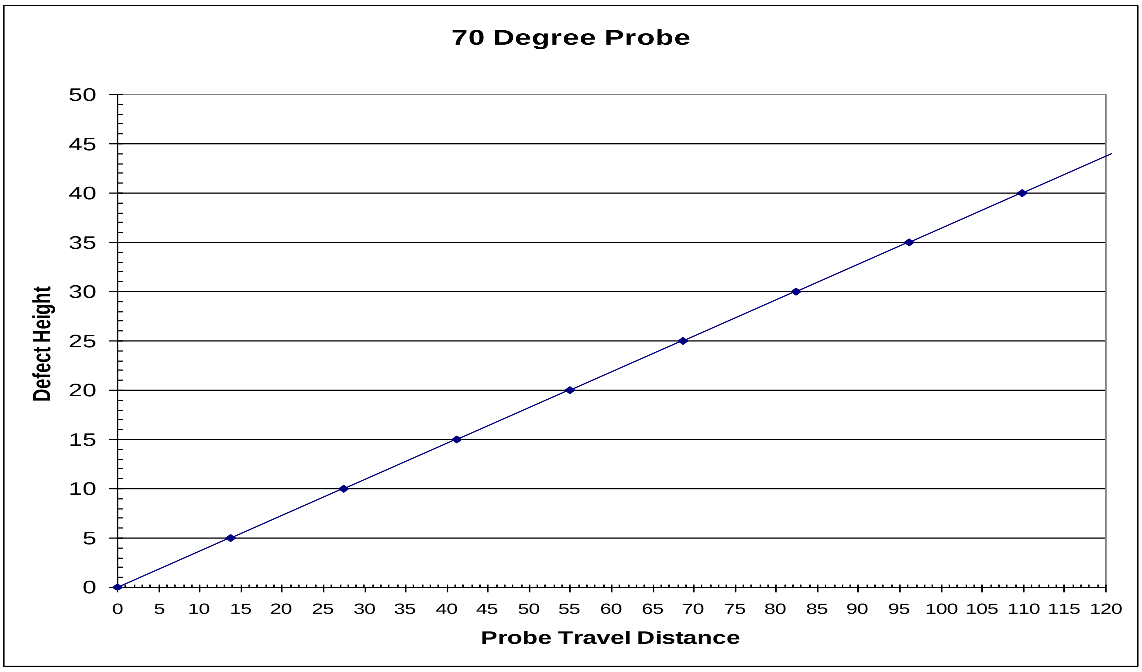


Figure 13 - Sizing defects using 70°♂ probe

On some digital machines the defect height can be calculated directly from the unit display.

When Transverse head defects need to be recorded as a percentage of head area, Table 12 can be used. This estimates the percentage loss of area in the head for transverse defects (TD's) in the rail head. This is an acceptable approximation, if the rail is not curve worn. If the head is worn, this should be noted on the defect report. **It is usual to classify the defect at a more urgent level of priority in curve worn rail.**

Table 13: Recording transverse defects as a percentage loss of head

PROBE TRAVEL 70°	PROBE TRAVEL 38°	DEFECT HEIGHT	% LOSS HEAD
< 27mm	< 7mm	< 10mm	< 5%
28 – 41mm	8 – 11mm	10 – 15mm	5 – 7%
42 – 55mm	12 – 15mm	16 – 20mm	7 – 10%
56 – 82mm	16 – 23mm	21 – 30mm	10 – 30%
> 83mm	> 24mm	30mm	>30%

Note: Defect height and percentage head loss taken from ETS-01-00 Section 1: Rail

For the purposes of calculating defect area, TD's are generally assumed to be circular.

% Head Loss is used in ETS-01-00 Section 1: Rail for: Transverse Fissures, Transverse defects from Shelling, Shatter Cracks, Engine Burn Fracture (Wheel Burn), Multiple Transverse Head Defects and Wire Feed Weld defects.

6.3.2 Width of Defect

Size for width using the "last significant echo" method. Most transverse defects are assumed to be approximately circular in nature. Where a width is desired; it is possible to get a rough measurement by marking the running face at locations where the defect echo starts and finishes. Note that working from a curved surface in a transverse direction distorts the result, making it difficult to obtain an accurate size of the defect in this direction. A straight edge may be used to control probe movement. Measure the probe travel width ways and record the distance.

Refer to ARTC Document, ETS-01-00 Section 1: Rail for classification and further action.

6.4 Sizing Defects using Zero Degree Probes

Size for length and, where required, height (VSH) using the last significant echo method.

The measurement is the same as the probe travel length. Record this figure.

Refer to ARTC Document, ETS-01-00 Section 1: Rail, for classification and further action.

Note: Any loss of back wall echo should be further investigated by visual inspection and scanning from the other faces of the rail, including using angle beam probes as per sections 6.3.1 and 6.3.2.

7 Recording and Reporting Requirements for Rails and Welds

7.1 Inspection Report – Ultrasonic and Weld Tests

Every ultrasonic test and weld geometry test undertaken shall be recorded on ETA0105F-01 Record and Report of Ultrasonic Test. Any defects found should be reported as per Section 7.2 Defect Reports.

A record of every ultrasonic test should be kept. The ultrasonic test records shall record (as a minimum):

- Date & place of test
- Areas tested

- Location of test
- Name of the operator
- Ultrasonic flaw detector (type, serial No)
- Probes used (type, serial No)
- Couplant used
- Reference to this procedure
- Test results
- Any variations from the requirements of this procedure
- Any test restrictions
- Rail temperature
- Any additional tests (dye penetrant etc) and results

These records can be kept electronically or through paper based forms such as ETA0105F-01 Record and Report of Ultrasonic Test (shown in Attachment A as an example).

A record of every weld test should be kept. The weld test report shall include:

- The weld number
- Date of test
- Location of weld
- Result of visual inspection
- Result of ultrasonic inspection
- Result of geometric inspection

These records can be kept electronically or though paper based forms such as “Weld Return Forms” or ETA0105F-01 Record and Report of Ultrasonic Test.

7.2 Defect Reports

Any internal or surface defect, in either the rail or weld, or any weld geometry defect, as classified in accordance with ETS-01-00 Section 1: Rail.

shall be sized and reported (ETA0105F-02 may be used). All these defects shall be entered into the relevant Works Management System. Engineering Manual RC 2400 Rail Defects Handbook gives more detail and information on these various defect modes.

This is to provide a record where a defect is found or if the geometry of a new weld is found to be substandard. This can be on an individual form, however when the continuous ultrasonic testing is carried out it is more likely to be stored in a spreadsheet.

7.3 Shielding Reports

Any areas of ultrasonic ‘shielding’ shall be reported. See ETA0105F-03 Rail Surface Condition Report. The report can be paper based or as an electronic database.

This can be on an individual form, however when the continuous ultrasonic testing is carried out it is more likely to be stored in a spreadsheet.

7.4 Site Marking

7.4.1 Rail Defects

Rail assessed as requiring remedial action or reassessment shall be painted yellow on the foot, web and side of head.

And where possible:

- The remove-by date, defect type and defect boundary could also be marked with white paint
- The priority of the defect can be marked with paint colours in addition to the yellow marking.

7.4.2 Weld Integrity

All new field welds when *ultrasonically tested* are to be sprayed with paint on both sides of the rail.

- Blue – if the weld is satisfactory
- As per 7.4.1 – if the weld is defective

7.4.3 Weld Geometry

All new field welds, when checked for *top surface straightness and alignment*, are to be sprayed with a paint dot on the web on both sides of the weld area approximately 100mm from the weld.

- Blue Dots – if the surface straightness is satisfactory
- Yellow Dots – if the surface straightness is not satisfactory.

The date of examination and identification code of the ultrasonic operator is also to be marked on the rail.

8 Part C – Periodic Calibration Methods

8.1 Calibration Methodology

The calibration of Ultrasonic flaw detectors shall be checked for the Instrument Features listed in **Error! Reference source not found.** (Section 4.2) in accordance with the procedures described below. These calibration checks shall be recorded on the appropriate form ETN0104F-01 Horizontal Linearity, ETG0103F-02 Vertical Linearity or ETG0103F-04 Calibration Block Register .

8.2 Horizontal Linearity (12 Monthly) Ultrasonic Flaw Detectors

8.2.1 General

Using the V1 block and Probe 5 (0°, 4 MHz) the horizontal linearity will be assessed for short range (approximately 100mm) and long range (approximately 500mm).

8.2.2 Procedure

- Place the probe on the V1 block at position H (see *Attachment A*), and adjust using the offset or delay to produce 6 backwall echoes. (Note Position H is looking at 25mm thickness and is assessing the linearity of the 125mm range)
- The 1st and the 6th echoes must correspond with the first and last vertical screen graticules.
- Adjust the 1st echo to 80% of the full screen height.
- Identify the location that the first echo breaks the baseline.
- Record this position in millimetres and mark the position on the graph shown on form ETG0103F-01 Horizontal Linearity.
- Bring each successive echo to 80% of full screen height and identify the location that each echo breaks the baseline.
- Echo positions within the linearity limits of ±2% are regarded to be acceptable.
- If the linearity limits of ±2% are not obtained, remove the machine from service, attach an out of service tag and advise supervisor.
- Repeat the above procedure with the probe placed on the V1 block at position F (Attachment A). (Note Position H is looking at 100mm thickness and is assessing the linearity of the 500mm range)

8.3 Vertical Linearity (12 Monthly)

8.3.1 General

Use the V1 block and Probe 5 (0°, 4 MHz) to assess the vertical linearity.

8.3.2 Procedure

- Turn all accessible suppression and sweep gain controls to the “OFF” position.
- Select a test range of approximately 250mm and place the probe on the V1 calibration block, at position H (see Attachment A).
- Select a back wall echo (BWE) which is adjacent to the centre of the screen (i.e. 5th Echo) and adjust the gain so that its height is 100% of full screen height.
- Decrease the gain control in increments of 2dB and record the echo heights in percentage of full screen height, to an accuracy of 1%.
- The results are recorded on the table on ETG0103F-02 Vertical Linearity and the results plotted on the graph.
- The resulting curve shall fall within the 2 dB linearity limits as shown on the graph.
- If the unit fails to be within the limits of ±2dB, remove the machine from service, attach an out of service tag, and inform supervisor for further action.

Note: *On analogue machines ensure the base line is correctly positioned before the machine is classified as defective. The position of the base line does affect the vertical linearity in the same manner as suppression.*

8.4 Calibration Blocks (2 yearly)

Inspect calibration blocks for condition every 2 years and record on ETG0103F-04 Calibration Block Register .

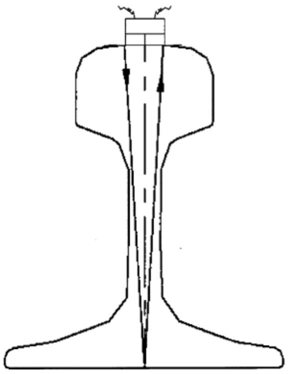
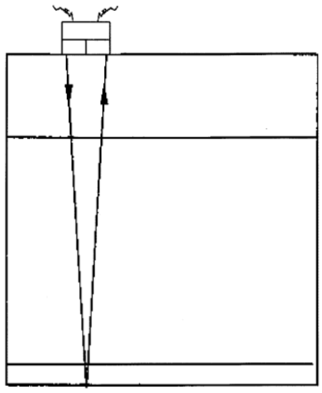
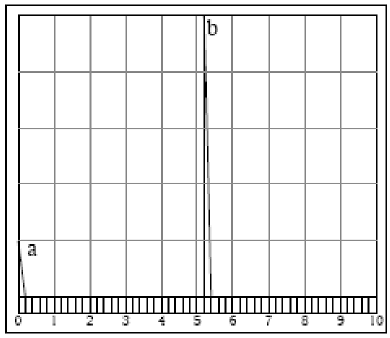
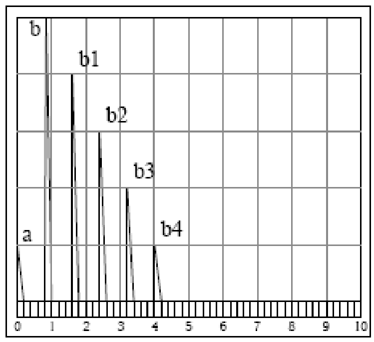
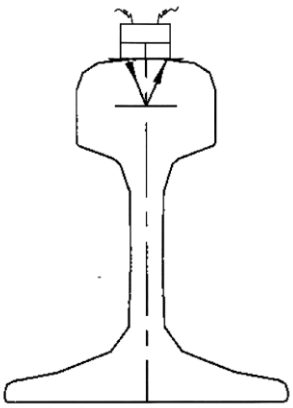
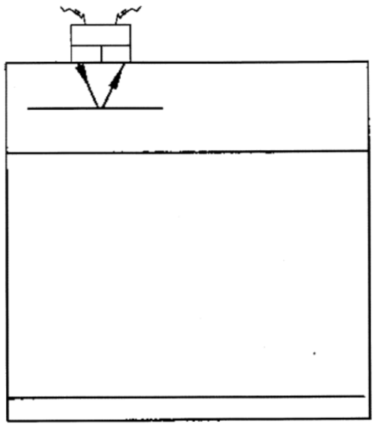
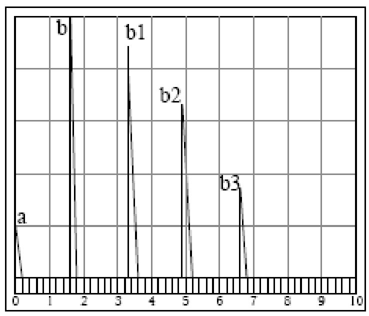
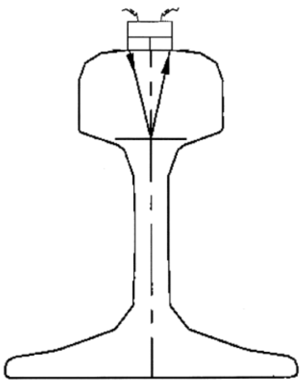
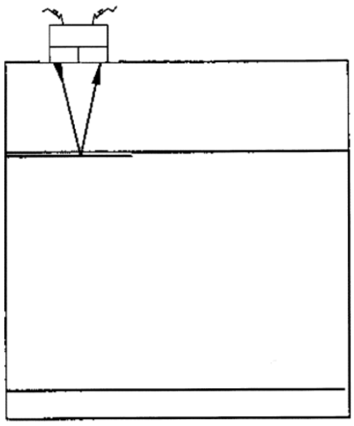
Inspect calibration blocks for condition: corrosion, chips, scratches etc.

8.5 Remedial action to be taken

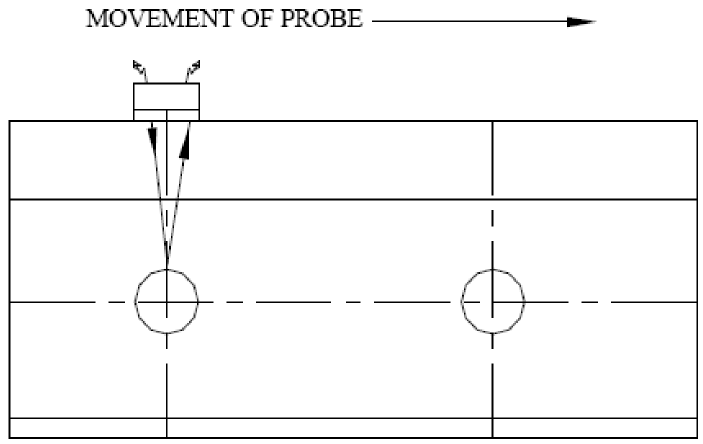
Tag and withdraw from service any equipment that fails to meet the calibration requirements.

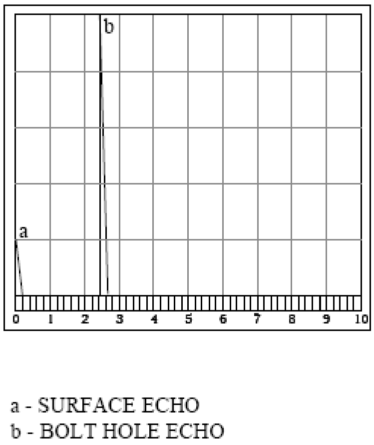
9 Part D – Appendices

9.1 Appendix A – Example Ultrasonic Readings for 0 Degree Probe

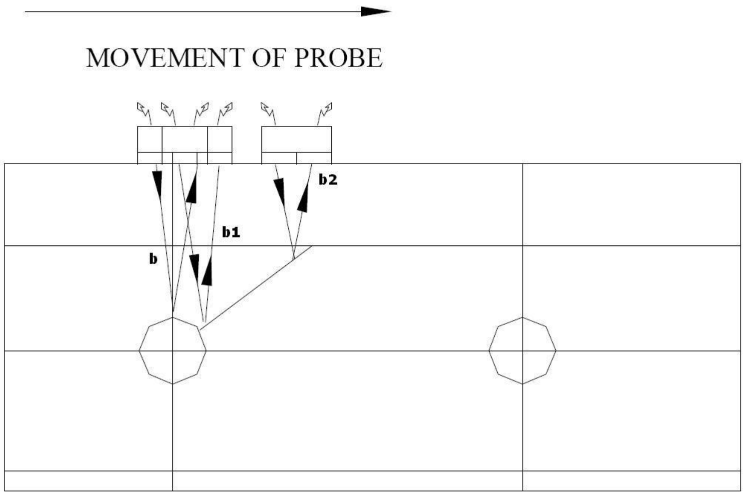
Rail Condition		Ultrasonic display
No Flaw 		 a - SURFACE ECHO. b - BACK ECHO.
Longitudinal horizontal split in head region		 a - SURFACE ECHO. b - FLAW ECHO. b1,b2 . . . MULTIPLE FLAW ECHOES
		
Longitudinal horizontal split in head-web junction		 a - SURFACE ECHO. b - FLAW ECHO. b1,b2. . . . MULTIPLE FLAW ECHOES
		

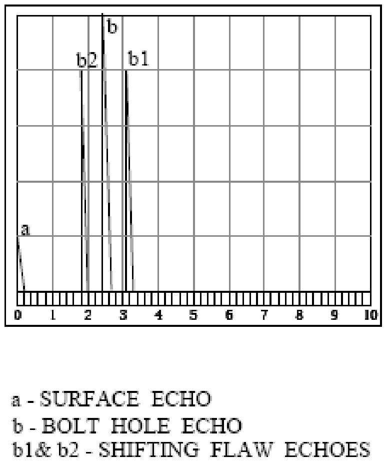
Bolt hole without crack





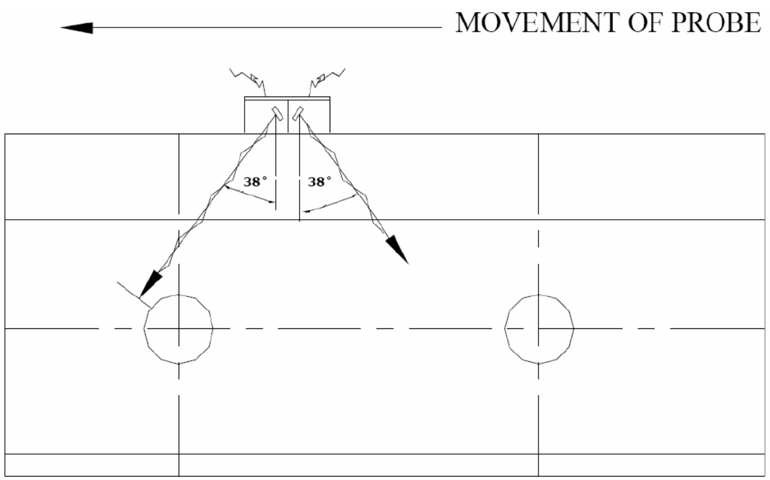
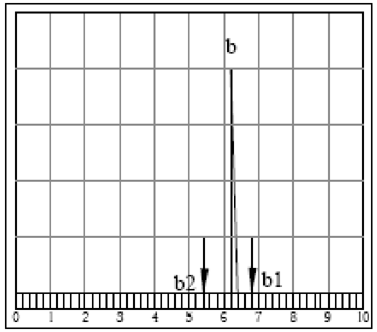
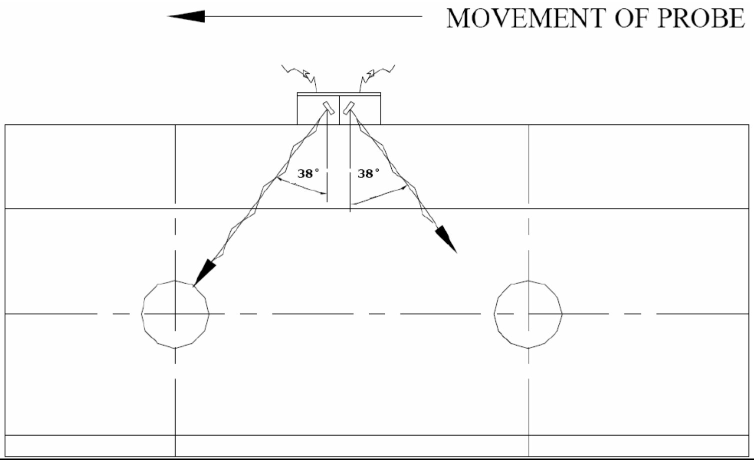
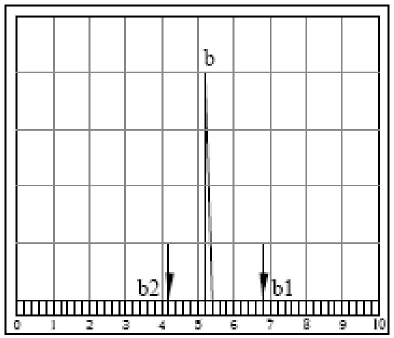
Bolt hole with crack





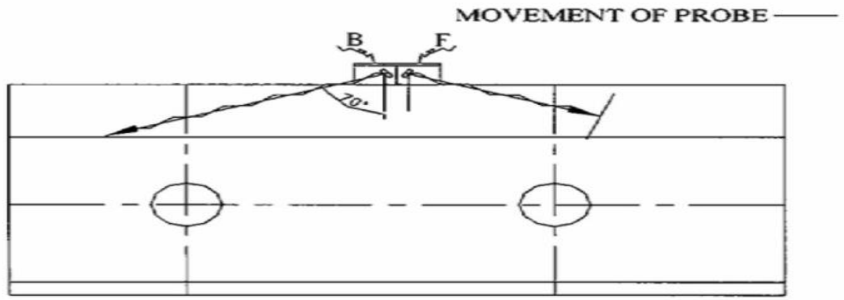
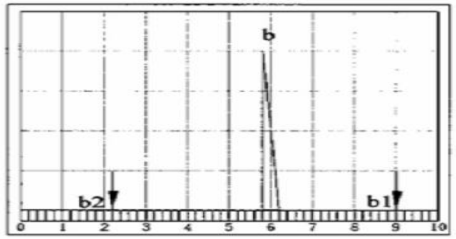
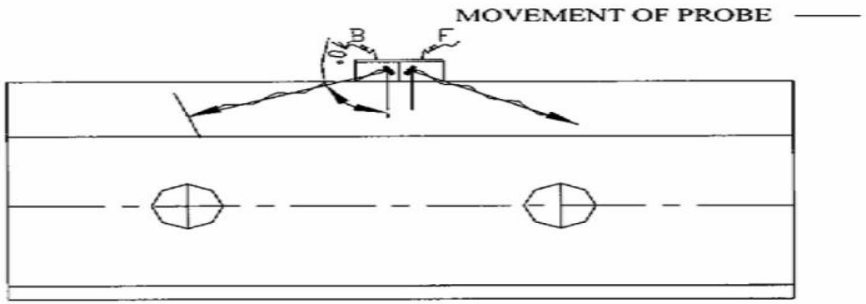
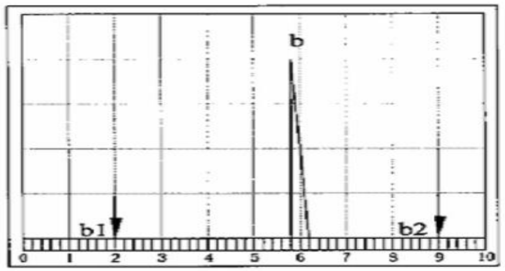
Note: *The bottom image is incorrect and the middle one is suspect. Bolthole cracks are normally tested with a 38 degree SU. Again this is taken from what would, or could be expected, when using a test trolley. Appendix B – Example Ultrasonic Testing Results for 38 Degree Probe*

9.2 Appendix B – Example Ultrasonic Testing Results for 38 Degree Probe

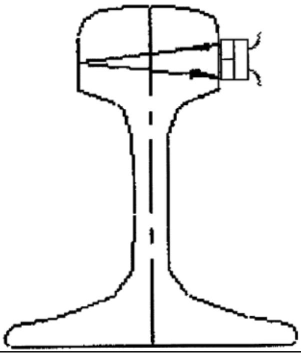
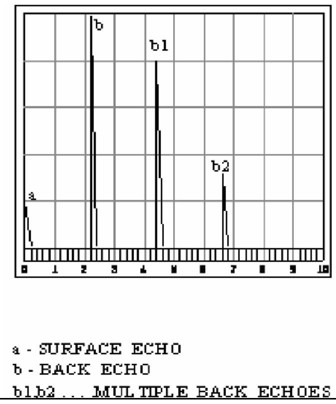
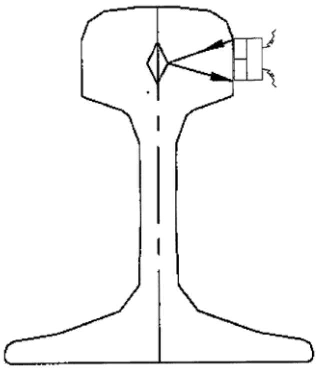
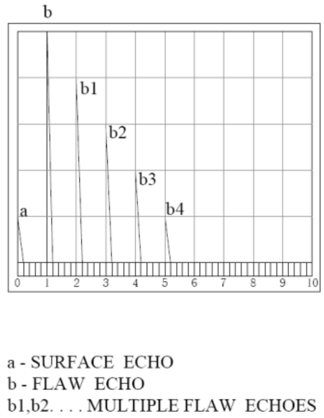
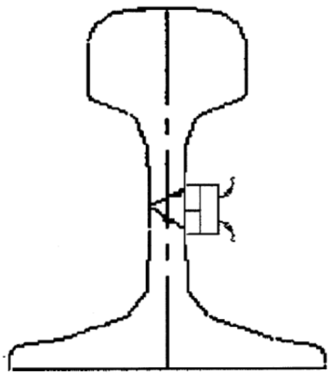
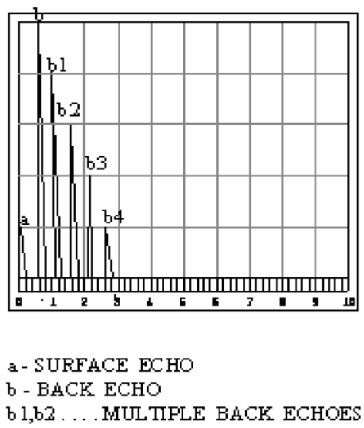
Rail Condition	Ultrasonic display
Bolt hole without crack 	 b - BOLT HOLE ECHO AT MAXIMUM AMPLITUDE b1 - BOLT ECHO STARTS APPEARING FROM HERE b2 - BOLT HOLE ECHO VANISHES HERE.
Bolt hole with crack in upper half 	 b - FLAW ECHO AT MAXIMUM AMPLITUDE b1 - FLAW ECHO STARTS APPEARING FROM HERE b2 - FLAW ECHO VANISHES HERE.

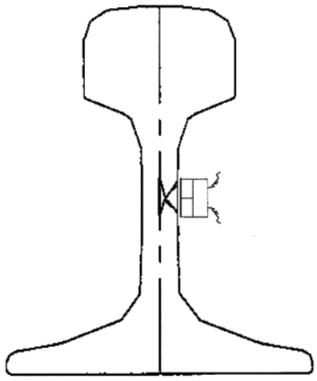
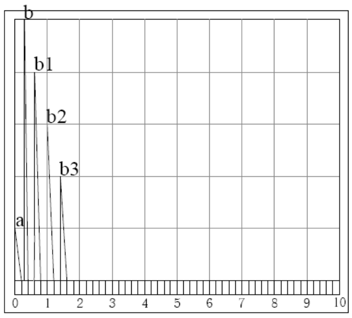
Shown using two single crystals (forward and rear facing)

9.3 Appendix C – Example Ultrasonic Testing Results for 70 Degree Probe.

Rail condition	Ultrasonic display
Transverse defect (forward probe) 	 b - FLAW ECHO AT MAXIMUM AMPLITUDE b1 - FLAW ECHO STARTS APPEARING FROM HERE b2 - FLAW ECHO VANISHES HERE.
Transverse defect (backward probe) 	 b - FLAW ECHO AT MAXIMUM AMPLITUDE b1 - FLAW ECHO STARTS APPEARING FROM HERE b2 - FLAW ECHO VANISHES HERE.

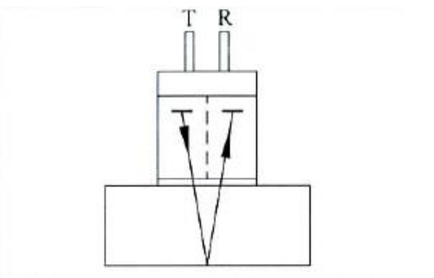
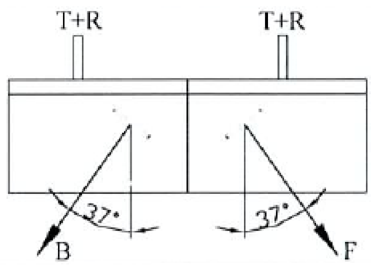
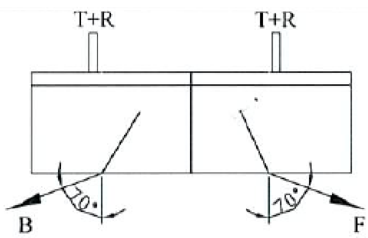
Shown with 2 crystals forward and rear facing

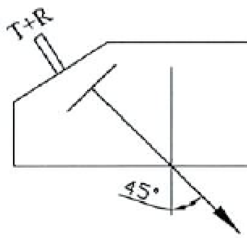
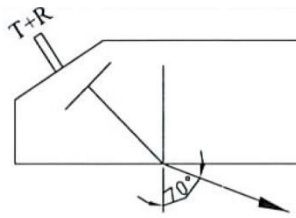
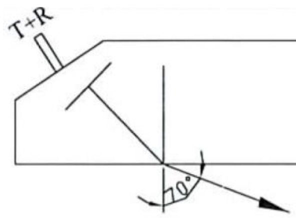
<table>
<tr><th>Rail Condition</th><th>Ultrasonic Display</th></tr>
<tr><td>Side Probing of rail head, Without Flaw
</td><td></td></tr>
<tr><td>Vertical Longitudinal split in head (0˚ Side Probing)
</td><td></td></tr>
<tr><td>Side Probing of Rail Web without Defect
</td><td></td></tr>
</table>

Rail Condition	Ultrasonic Display
Vertical Longitudinal split in Web (0˚ Side Probing) 	 a - SURFACE ECHO b - FLAW ECHO b1,b2 . . . . MULTIPLE FLAW ECHOES

Shown Single Crystal 10 mm 0˚

9.4 Appendix D – Alternative example of Probes used for testing of Rail and Welds.

S1 No.	Probe Angle	Beam Path	Application
1	**Probe 6 Twin Crystal Scan 1 and 3** 0˚ 4MHz Double Crystal		Longitudinal Horizontal defects in head web and foot
2	**Probe 2 scan 1 and 3** 37˚ Forward (F) and backward (B) 2MHz Single Crystal		Star crack in web. (BOLT HOLE)
3	**Probe 1 scan 1 and 3** 70˚ Forward(F) and Backward(B) 2MHz Single Crystal		Transverse defects in rail head.

4	45˚ 2MHz Single Crystal		1. Transverse Defects in head portions off.B and G.P welded joint. 2. Half moon defects in **Thermit Type** welds below web-foot Junction.
5	**Probe 1 scan 4** 70˚ 2 MHz (20mm Circular or 20mm x 20mm Square Crystal) Single Crystal		Defects of **Thermit Type** welded joints in Flange location
6	**Probe 6 single scan 4** 70 2 MHz Single Crystal (8 mm x 8mm)		Half moon defects in **Thermit Type** welded joints in flange

9.5 Appendix E – Guidance on ETA-01-05 Section 3.1: Existing Rail & Welds.

9.5.1 Executive Summary of Appendix E

The aim of this section of the standard is to have different inspection frequencies based on rail performance. The performance required is an average of less than 2 rail breaks per 100km on each line section. This will be achieved by a combination of hand or trolley testing localised areas, altering the frequency of the whole line testing with the ultrasonic car and targeting defined sections with increased testing of the ultrasonic cars.

The main aim of ultrasonic testing is to detect defects prior to the rail breaking.

If the rail break numbers are high then the ultrasonics is not being carried out often enough. Ultrasonic testing is not a perfect science. It is estimated that about 2/3 of the defects in the track are found with each run of the ultrasonic car. This leaves many defects in track undetected. The risk of a defect being undetected decreases as the defect grows. No contractor would commit to finding 100% of all defects on each run.

Changing the test frequency is a risk mitigation control. It will not change the number of defects developing each year but will reduce the risk of those defects becoming a broken rail.

There are many reasons to change the inspection frequency. The checklist on page 40 shows some of the factors that have been identified, however if every factor below were considered there would be a different testing interval required for every rail length.

This is not practical.

There is also not enough exact theory or data to support the changes required for each factor.

Therefore this standard bases the testing frequency on an average performance rate of 0.02 rail breaks per km per year.

This equates to 2 rail and weld breaks per 100km of track each year. Over a 10,000km network this would give approximately 200 rail and weld breaks a year.

Section 1 gives some detailed guidance on how to apply this performance rate to optimise the testing frequency.

Section 2 gives some guidance on how to reduce overall defect numbers and factors that will determine the rate of defect growth.

Section 3 gives details of the importance of how remaining head area is critical in determining the defect growth rate.

9.5.2 Checklist of Factors that can Change Testing Frequency

There are numberous factors that can have an effect on the speed at which a rail defect will grow to critical size.

Any increase to the testing frequency shall be evaluated with respect to:

- Type of rail defect
- Size of the rail defect
- Whether the defect is isolated or whether multiple defects exist
- Grade of rail steel
- Rail Section Size
- Rail quality (cleanliness and steel specifications)
- Remaining fatigue life of the weld or rail (localised number of broken rails) Remaining rail head area
- Position of the defect in relation to welded or fish-plated joints
- The Annual MGT, condition, type and axle load of trains likely to pass over the defect
- Whether a temporary rail clamping system is fitted to the defect to support the rail head (including back hole fishing and ‘fly’ fishing)
- Maintenance intervention levels
- The Track support structure and particularly the condition of the adjacent sleepers and fastenings
- Rail surface condition
- Design Track geometry
- Track geometry condition.
- Internal rail stresses (residual stresses, curving stressing and temperature stresses)
- Local conditions: Presence of other risk/mitigating factors (viaduct, tunnels, switch and crossing, sidings)

Risk of rail break causing a derailment changes with:

- Presence of track signalling
- Number of other defects in rail section
- Temperature on the day

Other Factors which alter the desired performance rate, including:

- Strategic importance of route section
- Cost of unscheduled rail replacement
- Cost of testing
- Expeditious use of testing resources.

9.5.3 Section 1: Test Interval

It is recommended that each line section is tested at least once a year.

If the testing intervals are to be varied, the proposing officer must document the basis for the change.

The recommended maximum variation is:

- In the case of a shorter interval: The new testing interval shall not be shorter than 1/3 of the previous interval.
- In the case of a longer interval: The new testing interval shall not be longer than 1½ times the previous interval.

9.5.3.1 Reasons for changing Test Interval

The main factors to consider when proposing a change in test frequency are:

- Broken rail rate per kilometre
- BRΦ - The percentage of breaks to total defect number
- Presence of high risk location
- Planned changes in rolling stock conditions

Table 14 – Crieria for adjusting test interval

TAKE THE WORSE OF:				
BROKEN RAIL RATE / KM	**BRΦ (% OF BROKEN RAILS TO TOTAL DEFECT COUNT KM**	**RAIL CONDITION**	**IMMEDIATE ACTION**	**CHANGE OF FREQUENCY**
0.01		Acceptable		Consider Reducing Testing Frequency
0.02	<5%	Acceptable		
0.03	5%+ to <10%	Unsatisfactory	Analyse data. Start to look for possible causes. Monitor.	Consider Increasing Testing Frequency
0.04	10%+ to <15%	Unacceptable: Undesirable	Analyse data, inspect worse affected areas. Determine cause. Plan Remediation.	Consider Increasing Testing Frequency
0.05+	15%+	Unacceptable: Harmful	Analyse data and determine cause.	Consider Increasing Testing Frequency

TAKE THE WORSE OF:				
BROKEN RAIL RATE / KM	**BRΦ (% OF BROKEN RAILS TO TOTAL DEFECT COUNT KM**	**RAIL CONDITION**	**IMMEDIATE ACTION**	**CHANGE OF FREQUENCY**
			Remediation required or impose speed restriction.	

Note: BRΦ represents broken rails as a percentage of <u>all rail defects</u> per kilometre (this gives the percentage of rail defects that resulted in broken rails before they were found).

$$\text{BR}\Phi\ \% = \frac{\text{the number of broken rails}}{\text{№ Defects found by \{Ultrasonic car + Visual inspection + № Broken Rails\}}} \times 100$$

The following points give a guide to changing the inspection test frequency using the graphs Figures 14 & 15.

1. Determine the number of km over which the defect average would be most relevant to determining the inspection frequency NOTE
2. For the km section determined in 1, determine the:
   - No of broken Rails per km over the last year
   - Number of defects found by the track recording car over the last year per km
   - Location of any high risk locations
3. Calculate the BRΦ % (% of rail defects that resulted in a broken rail in track)
4. Determine the multiplier factors from the MGT multiplier graphs (Figures 14 & 15).
5. If one of the factors <1 and one > 1 use only the < 1 factor, otherwise take the average of the two multiplier factors and multiply this by the current rail inspection frequency.
6. Apply the rule of “Not less than ⅓ and not more than 1½ times the previous interval”
7. Apply the rule of “Each line should be tested at least once a year”.
8. Apply check of new frequency to high risk locations determined in 2.

NOTE If there are any defect or broken rail clusters along the track, these need to be assessed and treated separately.
These numbers can be removed from the analysis so as not to skew the remaining averages
If most of the defects occur in one 50km section, the choices are: to increase the testing frequency over this 50km; or to increase the whole line to suit this 50km section.
If all of the broken rails are in the first half of the line, you may wish to examine this half of the line separately. There is more discussion on this in section 2 “Guidance on Defects Numbers”.

9.5.3.2 Graphs to help determine changes to the inspection test frequency:

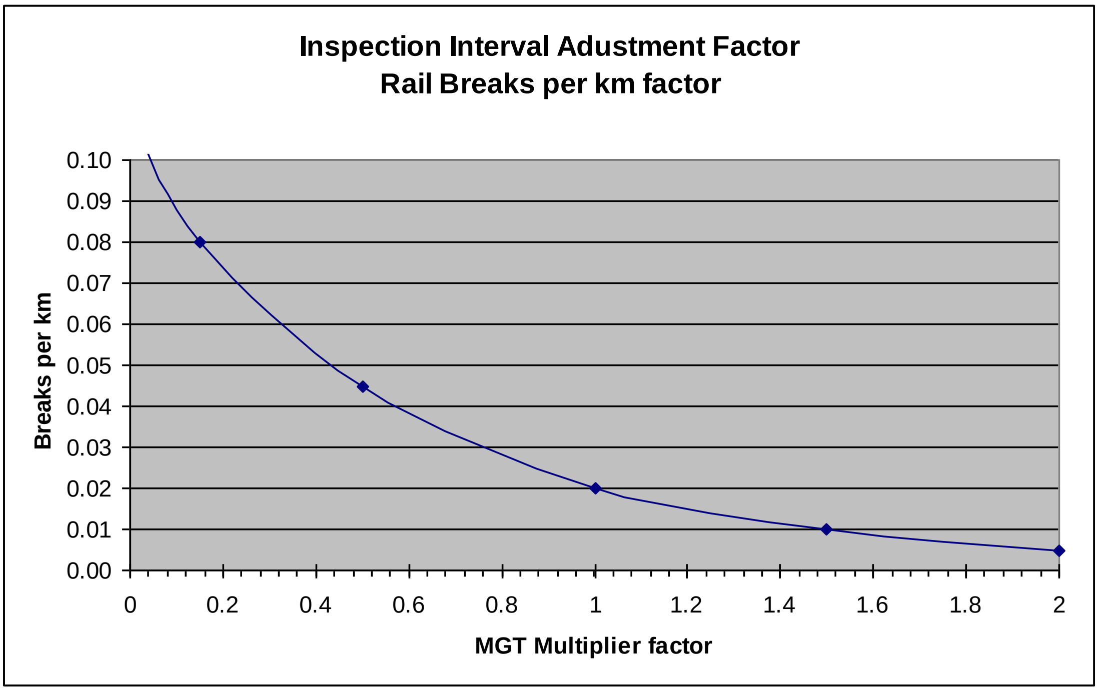


Figure 14 - Broken rail rate per kilometre

Use the 'MGT multiplier factor' to reduce or increase inspection frequency.

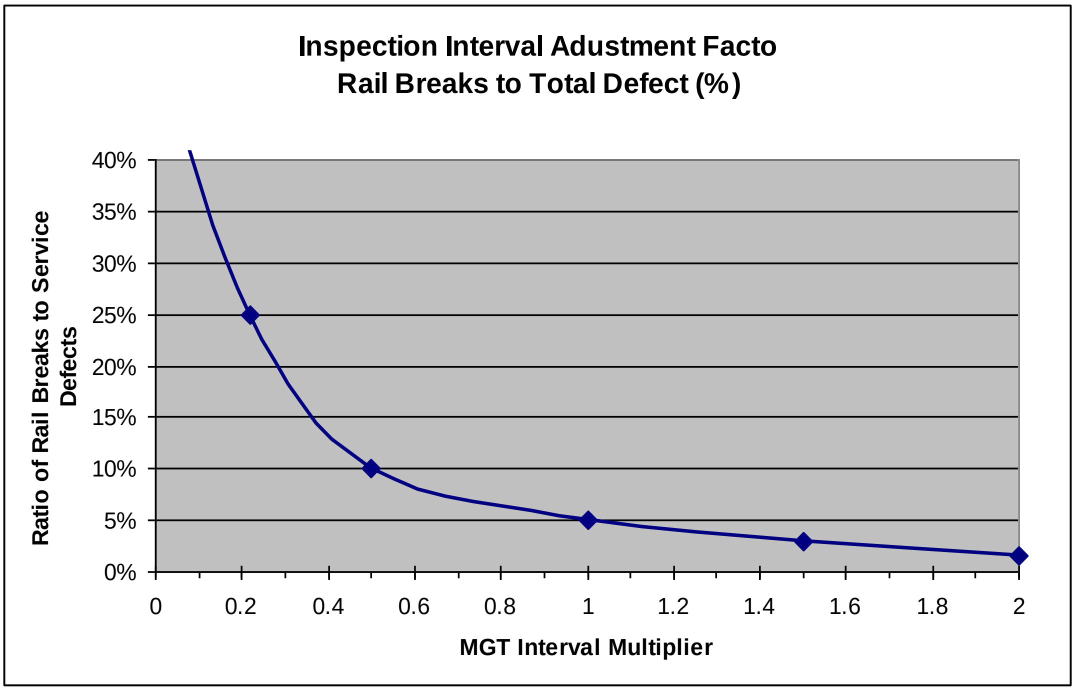


Figure 15 - Percentage of breaks to total defect number

9.5.4 Section 2: Guidance on Defect Numbers

9.5.4.1 Horses for Courses

The total number of defect found per year can only be reduced by addressing the reasons for the defects.

Increasing the testing interval will not reduce the number of defects found per year.

Increasing the frequency of testing helps manage the risk of in-service rail breaks.

Increasing the testing interval will reduce the number of defects found each run and reduce the number of defects found by other means (i.e. Signalling faults or broken rails reports).

9.5.4.2 Analysing Defect Numbers

The number of defects per km can vary considerable at different locations along any one track segment. Below are the defect numbers in each 50km segment from Adelaide to Wolseley (317km long)

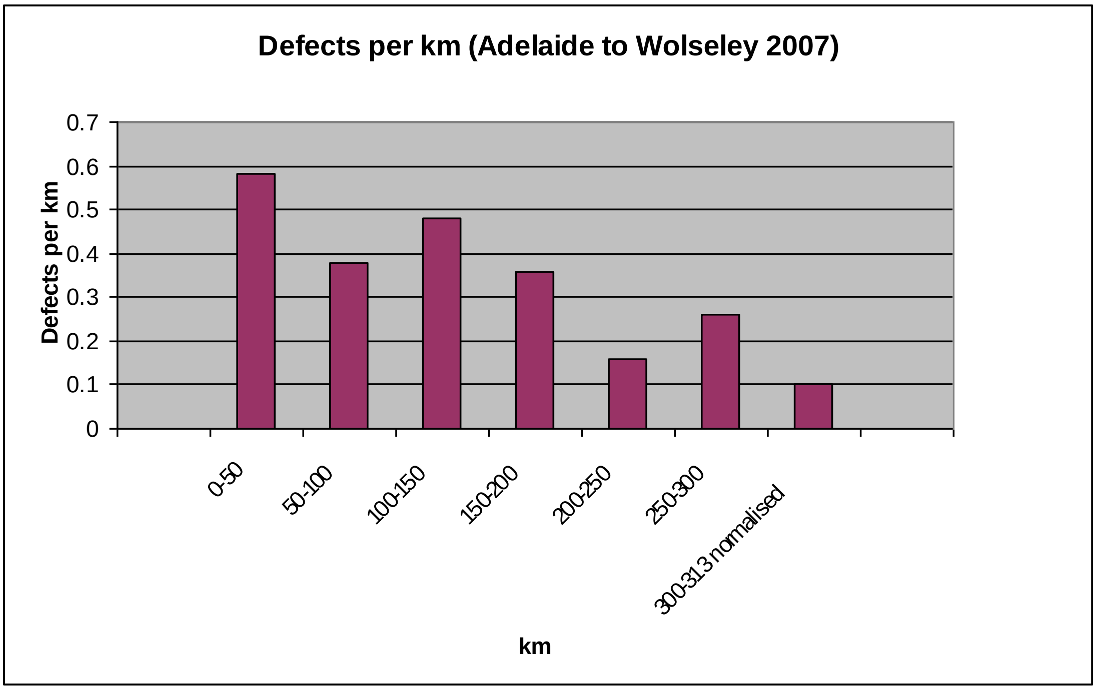


Figure 16

If the defect number per km averages more than 0.4 defects/km over 50km (or 0.3 over 100km) it would be prudent to plot the defects along a linear axis and look for clusters - i.e. the first 50kms is shown in figure 17.

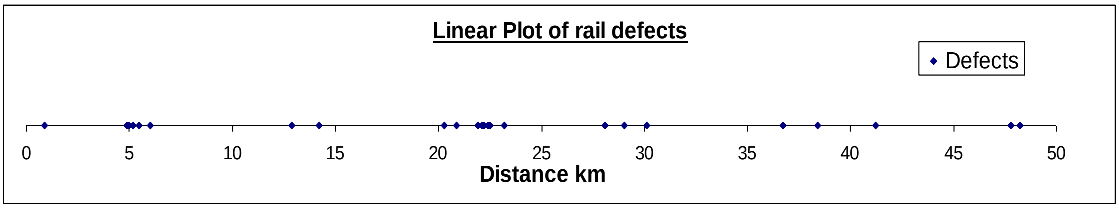


Figure 17

In areas of very high defects (4/km in any one in a year) the track should be inspected to determine if there is an underlying cause for the defects.

In the case above, investigation of the high defect numbers at around the 5 and 22km mark may determine the reason for these clusters of rail defects.

This investigation should include a site inspection of the rail (where the cause of the rail break will probably be staring you in the face!) It could also include a desk top study of available data; track geometry charts, curve and gradient diagrams, rail head profile records, stressing records, rail data (size and age).

9.5.4.3 Ways to reduce Defect Numbers

There are two reasons for high defect numbers: Excessive Forces & Weak Rail.

- Excessive forces can be caused by:
  - Large Ambient temperature differential and Neutral temperature
  - Dipped welds/joints
  - Flogging track, mudholes
  - Wheel flats
  - Poor wheel or rail profile
  - Track Curvature
  - Poor track geometry (especially on curved track)
  - Missing sleepers, high axle loads
- Reasons for Weak Rail:
  - Poor quality rail
  - Worn rail
  - Fatigued rail (bending fatigue and rolling contact fatigue)
  - Damaged rail (old hammer strikes or wheel burns/strikes)
  - Small Rail Section

A high defect count will probably be due to a combination of the above factors.

A study in America showed from a mixture of in track trials and desk top calculation that an average defect would 'grow' over 52 MGT. The graphs they produced from this are shown in figure 18.

'Temperature Differential' was considered the most significant factor which could vary the length of time it took for a defect to grow. Temperature Differential is the difference between the rail temperature and the temperature at which the rail experiences no longitudinal thermal force (stress free temperature).

From figure 18 and table 13, if all other factors were constant:

- with a temperature differential of 0ºC the defect growth rate is 110MGT
- with a temperature differential of 7ºC the defect growth rate is 52MGT

with a temperature differential of 60ºC the defect growth rate is 8.5MGT.

Note: *BEWARE: This study considered 68kg rail on wooden sleepered track in America and only analysed a relatively small sample of defects (approximately 30). There are many differences between American track and ARTC's, which makes it unwise to use their exact numbers directly for our tracks. However it is likely that the relativity of most of the factors would be similar.*
In ARTC track Head wear is likely to have more influence that shown in figure 5. In the study side Wear of 20% was considered the worst case and this reduced the growth life to 20MGT. Bearing in mind that 20% side wear of a 68kg rail has the same head area as

a 3% worn 47kg rail but is still a 62.5kg of rail per m! This would mean that a 20% worn 47kg rail could be expected to have an even greater detrimental effect than shown in the graph.
(From this it is easy to see that a 60% worn 60kg rail is likely to result in a growth rate of far less than the 20MGT shown below. It could be as little as 5MGT.

For instance a 60% curve worn 60kg rail carrying 30T axel load with 80MGT per year would probably need to be ultrasonically inspected every 2 to 3 weeks. The only way to reduce this inspection frequency would be by re-railing.

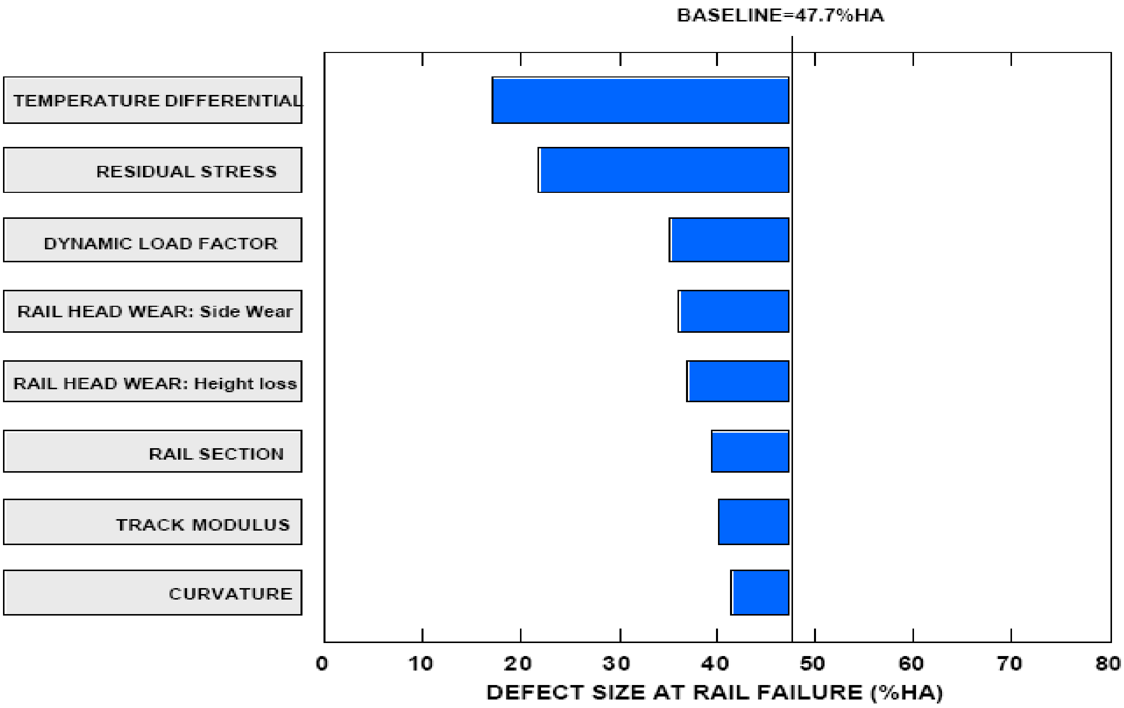


Fig 18 - Relative effect of various factors on slow crack-growth life of detail fractures

Table 15: Range values assumed in sensitivity study for slow crack-growth live of detail fractures

FACTOR	**CRACK GROWTH LIFE**		
	MINIMUM	**BASELINE**	**MAXIMUM**
Track Design and Maintenance			
Curvature	220m Curve	Tangent	Tangent
Rail section	85 ASCE (42.1kg/m)	136 AREA (67.4kg/m)	155 PS (76kg/m)
Track modulus	1 ksi*	3 ksi	10 ksi
Vehicle dynamics*	DLF=1.95	DLF=1.85	DLF=1.75
Operations and Mechanical			
Wheel contact centre	Far field side	Gauge side	Far gauge side
Static axle load	10 tons	16.5 tons	39 tons

Other			
Temperature difference	Δ*T*=60˚C	Δ*T*=7˚C	Δ*T*=0˚c
Rail head wear	20%HA	0	0
Residual Stress	30 ksi	10 ksi	10 ksi
Location of defect	1.3mm below	Nominal	Nominal

*ksi = kilopound per square inch

Note: DLF refers to the dynamic load factor which is used as a multiplying factor on the baseline value for static axle load.

9.5.4.4 Section 3: How Remaining Head Area can effect defect growth rates

Where there are several different sizes of rail in a track section remaining Rail Head Area should be considered as amount of remaining mm2. Consideration should also be given to the remaining profile shape.

The proposed ARTC CoP Wear standard allows:

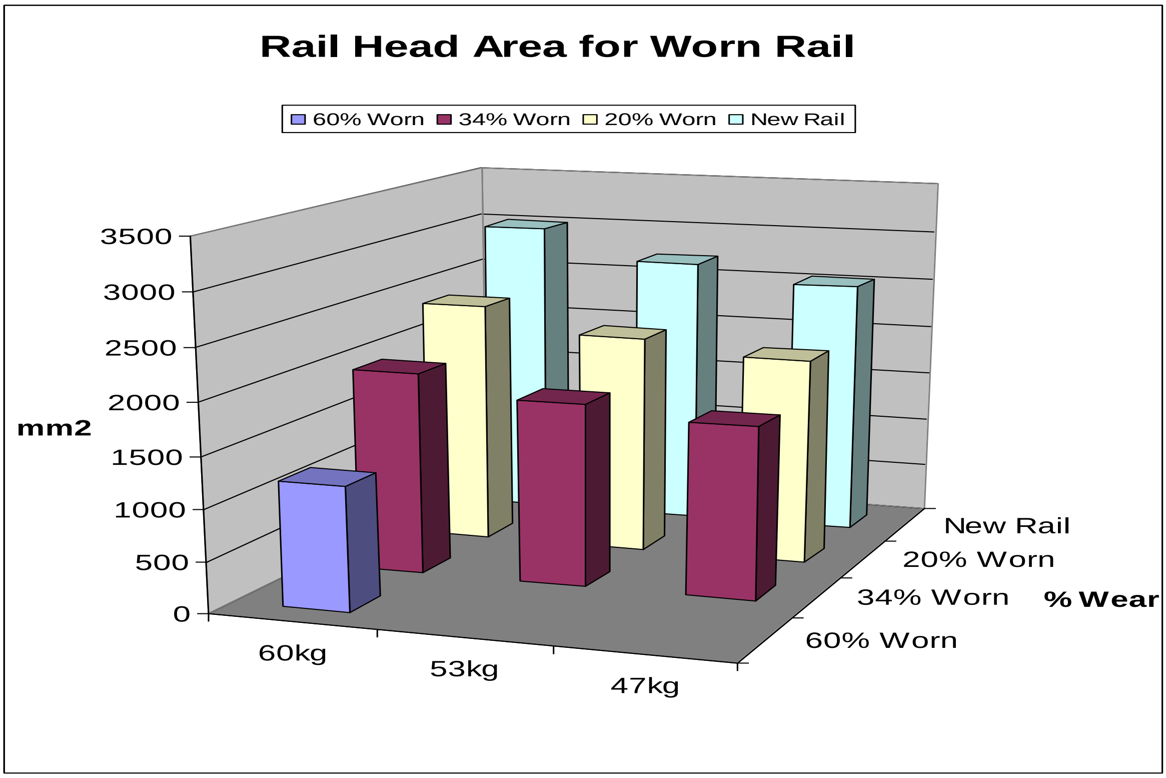


Figure 19a

Or

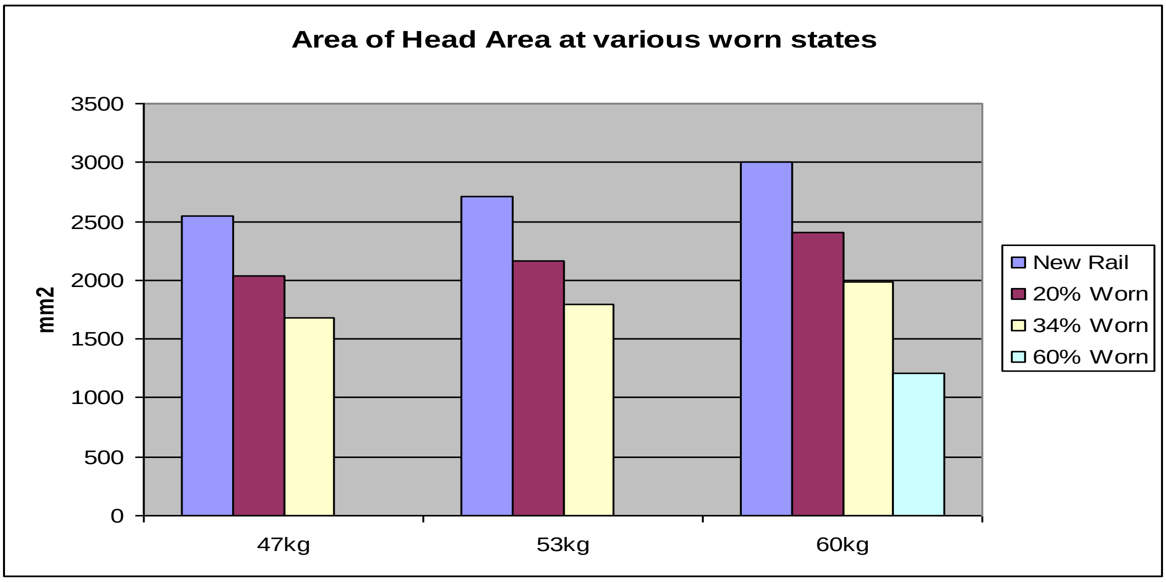


Figure 19b

As rail wears it becomes less able to tolerate defects. An elliptical, 20mm deep, Transverse Defect in a brand new 60kg rail would take up 21% of its head area.

The same 20mm deep TD in a 60% worn 60kg rail would take up 50% of its head area.

This means that less tonnage (MGT) is needed for a defect to grow to a critical size as the head gets smaller.

Approximately 'critical size' is shown when the curve intersects the 'Breaking Point' line.

Below is a graph showing how much an increasing elliptical defect decreases the remaining head area for different sections of rail at different worn states.

Note: *Defects below 10mm in height are very difficult to find by ultrasonic testing. To catch a defect in 60% worn rail before the rail breaks, requires ultrasonic testing at a ¼ of the frequency of new 60kg rail.*

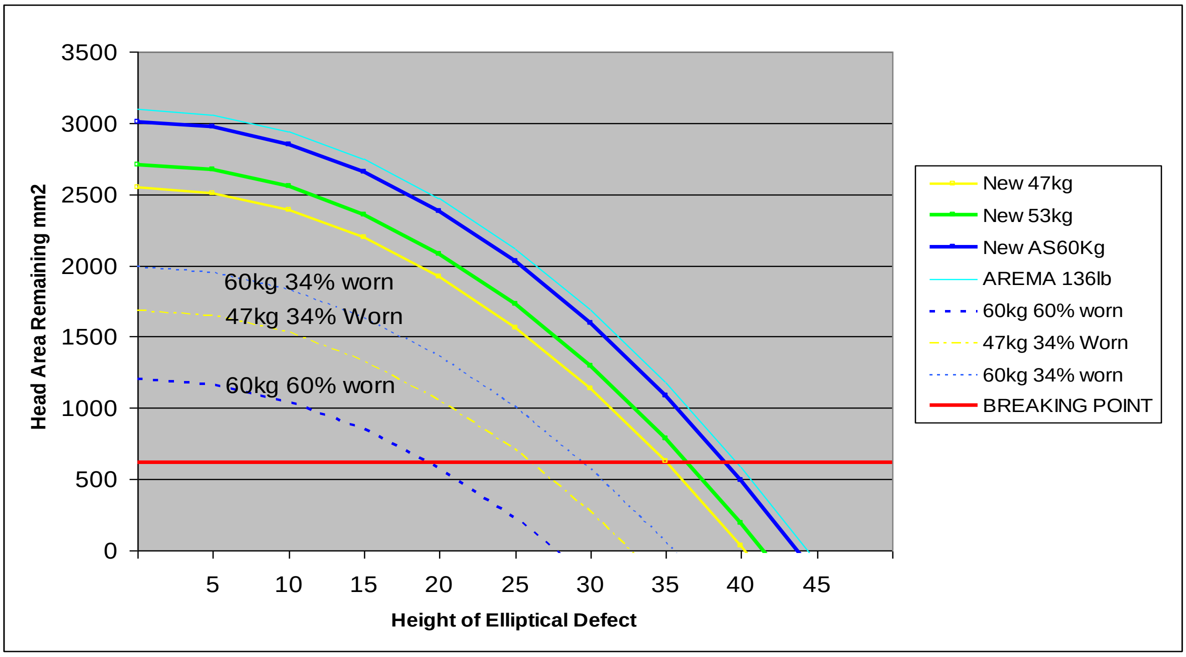


Figure 20

9.5.4.5 Theoretical Example of different crack growth rates for different rail sizes:

115RE = 57kg/m with a head area similar to a AS47Kg rail

132 RE = 65kg/m with a head area half way between an AS53Kg and AS60kg rail.

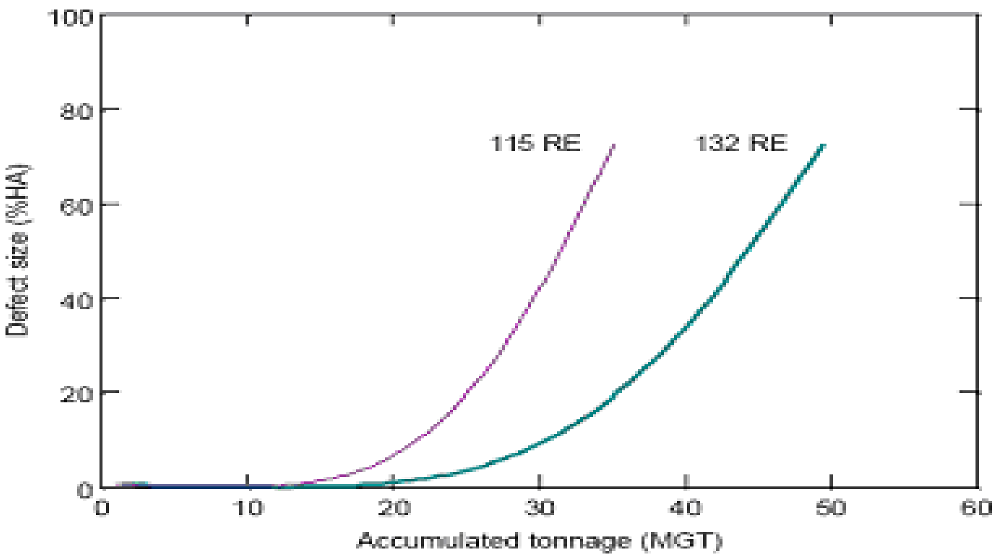


Figure 21 - Comparison of assumed crack-growth curves for detail fractures in 115 RE and 132 RE rail.

9.5.4.6 Some examples of reducing the broken rail rates (Service Defects) with reduction in frequency of testing

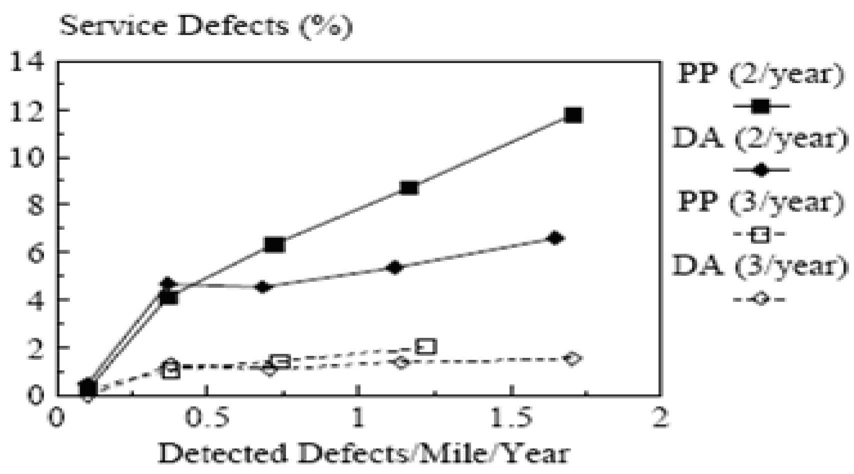


Figure 22 - Effect of inspection interval on service defects for 60 MGT per year traffic density.

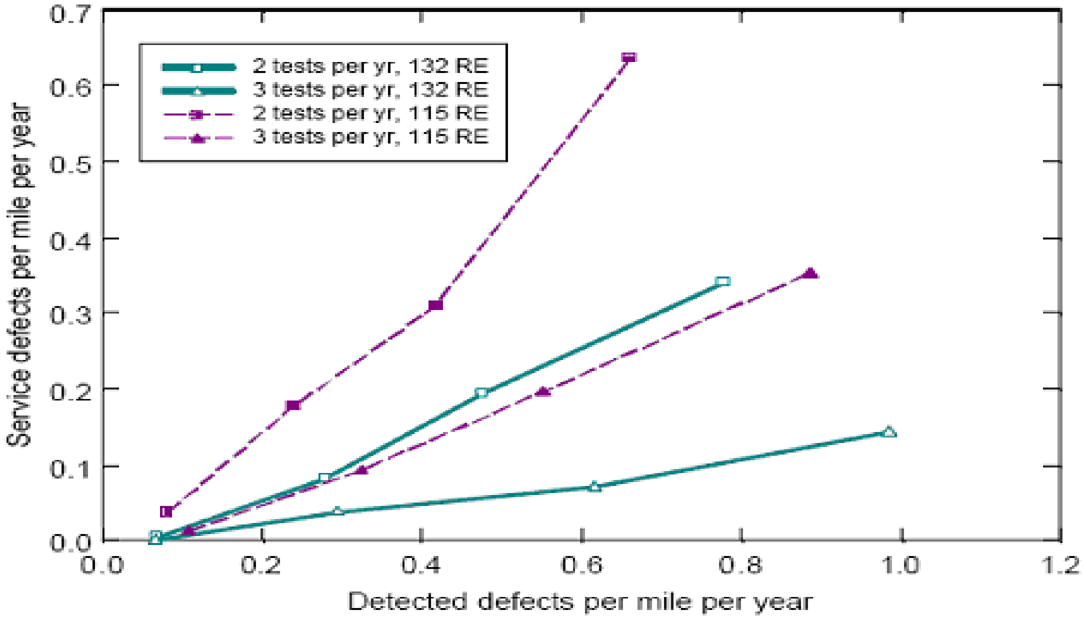
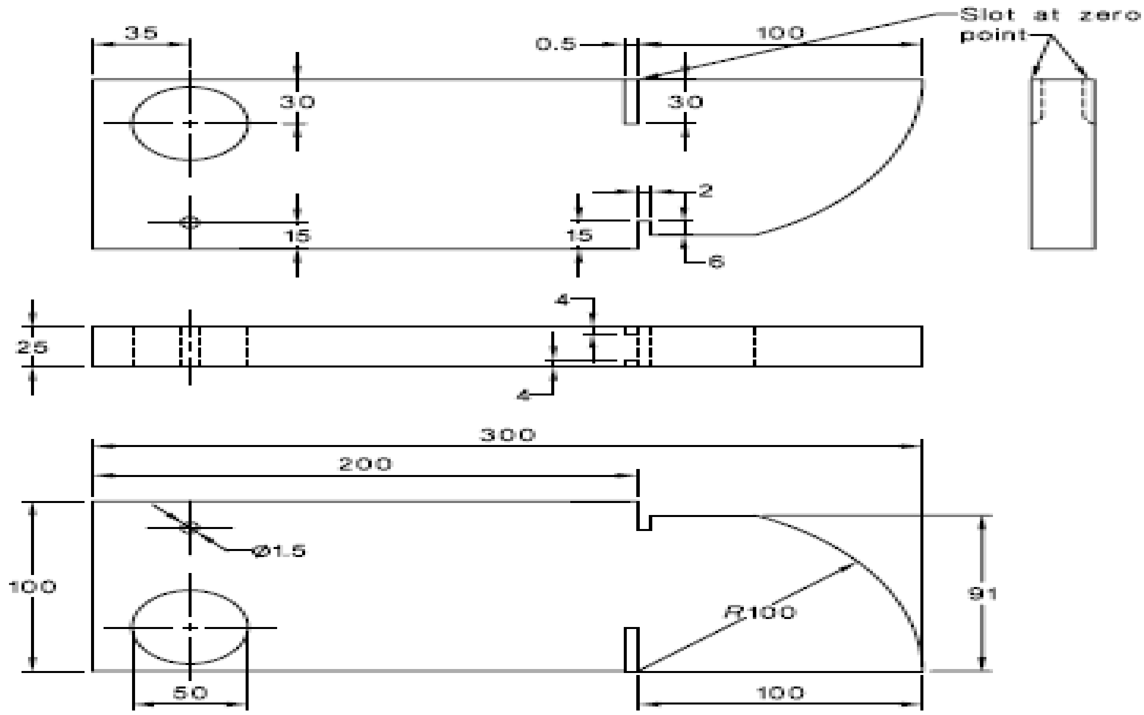


Figure 23 - Effect of rail size and inspection frequency on service defect rate

10 Part E – Attachments & Forms

10.1 Attachment A – Calibration Block No 1 (Copied from AS 2083 – 2005)



DIMENSIONS IN MILLIMETRES

FIGURE 2.1 DIMENSIONS OF CALIBRATION BLOCK NO.1

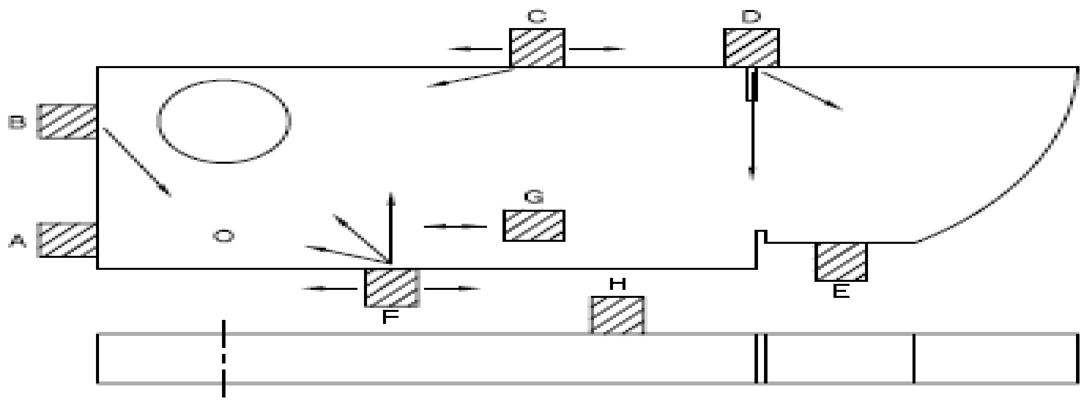


FIGURE 2.2 PROBE POSITIONS FOR BLOCK 1

10.2 Attachment B – Calibration Block No 5 (Copied from AS 2083 – 2005)

Dimensions in millimetres