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1 Purpose

The purpose of this handbook is to explain how site welding is used in track maintenance and renewals work. The aim is to provide managers responsible for maintaining the track asset with guidance that will help them to decide:

- ◆ when and where welding is appropriate
- ◆ how it needs to be carried out
- ◆ when the work has been satisfactorily carried out.

2 Scope

This handbook covers all the current welding practices used on LU, for the joining and repairing of both running and conductor rails.

3 Introduction

This handbook is one of a series intended to help those responsible for managing the track asset achieve standards and meet LU corporate objectives. This handbook offers:

- ◆ practical advice on track activities
- ◆ guidance on choices and alternatives
- ◆ 'do's and don'ts' for use on site
- ◆ technical data and illustrations
- ◆ material to use in staff training.

Before you first use this handbook, you should familiarise yourself with its contents. The subject headings are set out in the Contents list.

The technical background of the welding processes is described only in sufficient detail to give an appreciation of the factors that influence the choice of rail welding technique.

You will find in this handbook notes and comments based on the day-to-day experience of staff, outlining methods they have found successful in particular conditions as well as points not to be overlooked in carrying out the work.

At the end of each section there is a list of sources of further information. **In the event of any conflict between this handbook and LU standards, the latter shall prevail.**

4 Welding as a track activity



Welding allows rail material lost through wear and deterioration to be replaced by new metal, and so provides a means of extending the life of rails. It also enables short lengths of rail to be joined into long welded rail, and long welded rail to be formed into continuous welded rail. Table 1 lists the wide range of welding techniques available: the underlined items are carried out by LU.

4.1 Understanding the material being welded

Figure 1 illustrates the sections and grades of running rail used by LU, as defined in S1157 (which refers to EN 13764, the European standard for rails which describes a range of profiles and grades). The figure also shows the branding marks which are used to identify the rail grade, so that the appropriate welding procedures and consumables may be used. Note that the designation "113A" is shown as "56E1" on current rail deliveries, and "BSC Workington" etc is now "Tata SC".

Table 1: Rail welding processes and use							
Workshop			Site				
Flash butt	Alumino-thermic	Electric arc	Flash butt	Alumino-thermic	Electric arc	Arc brazing	Powder spray
Manufacture of CWR and LWR Construction of crossings Construction of switches	Construction of crossings Joining of different rail sections	Construction of crossings Repair of crossings	Joining of rails	Joining of rails Bond attachment Weld replacement	Maintenance and repair of rails and crossings Track circuit deposits Bond attachment	Bond attachment	Surfacing of dipped welds Track circuit deposits
The underlined items are carried out by LU.							

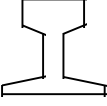
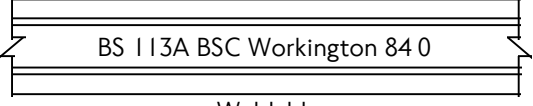
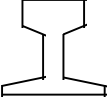
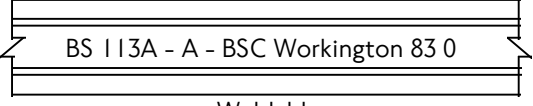
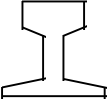
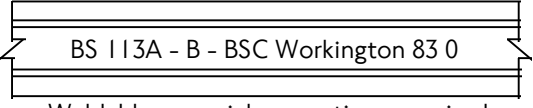
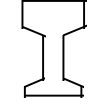
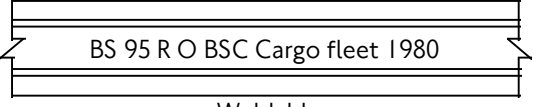
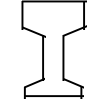
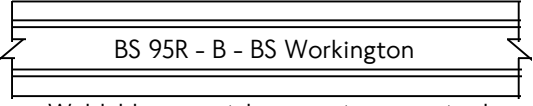
Rail section	Identification rolling marks	Steel type
1 	 Weldable	Normal grade
2 	 Weldable	Grade A 2 blue bands
3 	 Weldable - special precautions required	Grade B 3 blue bands
4 	 Weldable	Normal grade
5 	 Weldable - special precautions required	Grade B 3 blue bands
The branding marks and their meanings, and the current equivalent markings, are given below:		
Markings	Meaning	Present equivalent marking
BS 113A	113A profile, now designated 56E1	56E1
A	the rail is grade A, now designated R260	
B	the rail is grade B, now designated R350HT	
BSC Workington, (or Cargo Fleet)	the rail was made by British Steel at Workington (or Cargo Fleet)	Tata SC (i.e. rolled at Scunthorpe)
83	the rail was made in 1983	same (i.e. last two digits of year)
O	indicates the steel was made by the basic oxygen steel process	nil

Fig. 1 Illustration of rail branding marks on LU

The identification of rails can sometimes be difficult, since the system of marking rails has changed over the years. A unified system was introduced in 1978 for rails produced in the UK by the British Steel Corporation. It has since been further changed to reflect the change in BSC's ownership and the use of the EN 13674 profile and grade designations.

Pre-1978 rails

The rails are generally marked with the following information:

Rail section	Manufacturer's name or place	Year of manufacture	Manufacturing process or detail
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Post-1978 rails

The rails are marked with the following information:

Rail section	Grade of steel	Makers name or place	Last 2 digits of year of manufacture	Steel making process	Purchasing administration
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EN 13674 gives full descriptions of the branding marks likely to be seen on rails now being delivered to LU. Paint bands are applied by the manufacturer at the rail ends, but should not be relied upon for identification of other than new rail.

Rail steels are designed to have sufficient strength and durability to give good resistance to wear and to minimise the risk of fracture, whilst still being readily weldable. There is a wide selection of rail steels available to suit train axle loads, speeds and layouts, and improvements are continually being made to produce rails which are stronger and better to resist the abrasion of railway traffic.

The types of rail used by London Underground, in plain line and junctionwork, reflect the intensive train service, curves and axle loads experienced, and these are listed in table 2.

Table 2: Normal track situations for rail steels	
Rail grade	Normal use
R220 (formerly BS11 Normal grade)	Jointed plain line, long and continuously welded rails, but no longer supplied.
R260 (formerly BS11 wear resisting Grade 'A')	Plain line and junctionwork (except cast crossings).
R350HT (formerly BS11 wear resisting Grade 'B')	Fabricated junctionwork.
Bainitic (TITAN)	Cast centre crossings in dense traffic areas. (Only small numbers exist and they are not being perpetuated.)
11/14% manganese (HCAMS)	Cast monobloc and centre-block crossings.

5 Maintenance welding of plain line

5.1 Wheelburns and squats

Maintenance welding is principally the repair of isolated wheelburns. This part of the handbook focuses on the identification and treatment of wheelburns. The technical welding procedures that are involved are discussed in section 7.



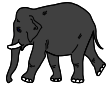
Wheelburns occur when train wheels slip on the rail head. The heat of friction rapidly raises the temperature of the rail to values of several hundreds of degrees Celsius. Not only is the rail physically gouged, but the heat makes the steel extra hard and brittle and susceptible to cracking on cooling. There are two types of wheelburn.

- ◆ Isolated wheelburns occur when the wheels spin with the vehicle stationary (refer to plates 1 and 2). Since all the damage is put in at one spot, these wheelburns can be very severe.
- ◆ Continuous wheelburns occur when the wheels spin with the vehicle moving slowly forward. These wheelburns are longer, but in general less severe (see plates 4 and 5).

Because of the way they form, wheelburns are seen on both rails and often in groups. They normally appear at locations on the rail where trains regularly stop and start, for example at the approach side of signals and gradients near signals and stations. Wheelburns also occur near rail lubricators where grease has been allowed to spread on to the head of the rail.

Where wheelburns are extensive or continuous on the rail head it is more cost-effective to replace the rail than to attempt weld repairs.

It is important not to confuse these isolated wheelburns (plates 1 and 2) with squats (plates 3 and 6). The latter can mask more serious defects such as tache ovale-type defects (refer to Track Handbook 23 *Managing rail defects*) and may therefore not be amenable to weld-repairing. Table 3 summarises the differences between wheelburns and squats.



REMEMBER!

The easiest way to distinguish between wheelburns and squats, is that wheelburns occur on both rails, opposite each other. Squats don't.

Table 3: Characteristics of wheelburns and squats			
Features of defect	Isolated wheelburn	Continuous wheelburn	Squat
Oval shaped defect on rail head	✓		
Pronounced depression on rail head	✓		
Similar defect on opposite rail	✓		
Similar defect on same rail at intervals	✓		
Old weld repair with flaking or crack	✓		
More than one oval shaped effect merged to give flowed or rippled appearance		✓	
Shallow depression on rail head			✓
Circular or wishbone shaped flaking			✓
Circular or wishbone shaped surface cracks			✓
Dark mottled patches on rail head			✓
Train tyre pattern widens over defect			✓



Plate 1 Shallow wheelburn which would benefit from profile grinding. After grinding welding would probably not be required

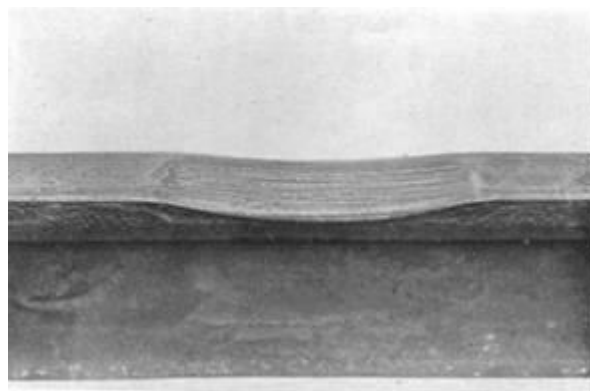


Plate 2 Severe wheelburn. This defect is reaching the limits for weld repair

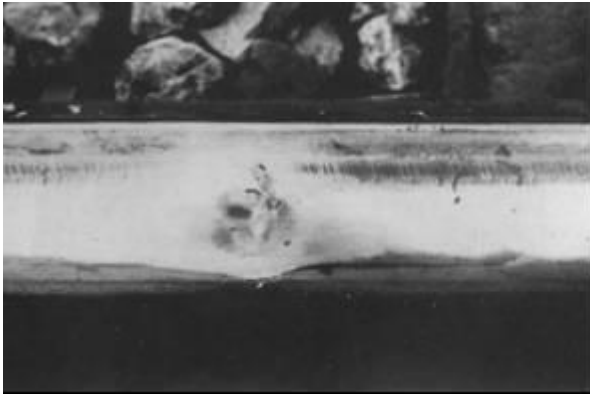


Plate 3 Squat type defect. Note wider tyre path and dark mottled area over defect

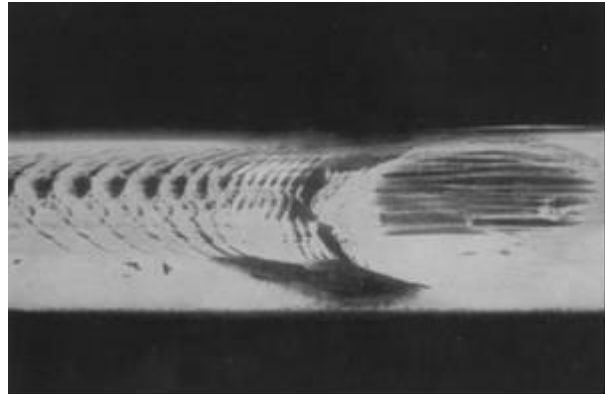


Plate 4 Wheelburn. Oval shaped scouring of rail leading to continuous wheelburn



Plate 5 Continuous wheelburn

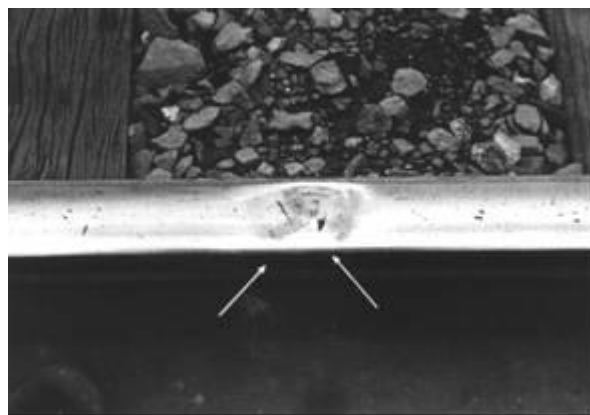


Plate 6 Squat. Note surface cracking

5.2 To weld-repair or not?

5.2.1 Introduction

It is cost effective to repair isolated wheelburns when:

- ◆ the rail is in good condition and not approaching its vertical or sidecut limits
- ◆ wheel slip is not a regular occurrence at the site
- ◆ the wheelburn is not associated with a tache ovale-type defect
- ◆ the wheelburn is about 5mm or more deep and causes noise
- ◆ the wheelburn is about 5mm or more deep and includes a crack.

On sites where wheels are prone to slip, profile grinding of the rail head using a rail mounted grinder to remove the burnt steel and reduce impact is an option, and generally leaves an acceptable level of rail head profile. Shallow depth wheelburns as illustrated in plate 1 may also be profile ground. In many cases this gives a good result and reduces noise and impact. Repeated welding of wheelburns may lead to rail fatigue problems in the long term. The fatigue risk is associated with the increased possibility of weld inclusions and continual alteration of the grain structure.

It is not cost effective to repair wheelburns when:

- ◆ they are continuous
- ◆ the rail head is damaged or corroded due to its site conditions, for example in damp tunnels
- ◆ they are less than 5mm deep, in this case the wheelburn needs to be profiled by grinding.

Weld repair is permitted within fishplate limits if there is no associated vertical defect greater than 15mm present – see T0436.

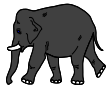
Weld repair of wheelburns needs to be undertaken within 7 days of reporting and ultrasonically tested within 14 days of the repair. Any agreed variation of the timescale needs to be based upon site conditions, for example line speed and local track conditions.

5.2.2 Preparatory work on track

Any maintenance work to correct general track defects in the welding area caused by trains (for example voids under sleepers) needs to be completed before welding starts. This ensures that the weld repairs are not subjected to severe lateral or vertical loadings. The following track maintenance work needs to be done as required before weld repairing:

- ◆ pack sleepers that have voids in the repair area
- ◆ tighten rail fastenings adjacent to the repair area
- ◆ correct the cross levels
- ◆ tighten any fishplates in the repair area.

The general condition of the track needs to meet the standards specified in S1159 prior to welding.



REMEMBER!

The welding process generates heat and sparks and the risk of fire needs to be assessed and safeguards put in place. If the repair welding is in an underground location a hot working permit is required. On a surface line, as far as possible any obvious fire risk materials or hazards need to be removed.

5.2.3 Welding the wheelburn

The damaged rail surface needs to be ground out and tested for cracks using the dye penetrant test. The ground area then needs to be welded in pads with the completed weld standing about 3mm proud of the rail surface prior to profile grinding. The procedure, including the dye penetrant test, is described in more detail in section 4 of this handbook.

5.2.4 Programming the work

In addition to the specific site and line details, the Workshop Manager/Section Track Manager will need to know the following information:

- ◆ the grade of rail
- ◆ basic details of any cracks present
- ◆ the priority of repair.

5.2.5 Post-welding examination

Equipment required for checking the repair

After repair welding, the repair needs to be examined. A 1m straight edge, a hand mirror and a wire brush for removing rust and debris are suitable for the examination.

◆ Profile grinding

Use the straight edge placed on the centre of the repair to check levels. A value of $\pm 0.5\text{mm}$ is the target, but this is not always attainable on older rail. The grinding needs to match smoothly with the existing rail head.

◆ Rail head

Visually examine the weld repair area, using the rail mirror to view the upper fishing angles. The repair needs to be free from any gross surface cavities, holes or trapped slag from the welding rod. If in doubt, any defects need to be examined by the Section Track Manager. Any defects may have to be removed by grinding and the area then rewelded.

◆ Track components

The welding process may have damaged some of the track components. Look for, and renew if required, any burnt screwspike ferrules and burnt wooden keys. Any burn damage to bonds, pigtails, track feeder cables and leaky feeder cables needs to be reported to the Line Service Centre for immediate repair by local signal staff or the Signal and Control Systems contractor.

◆ Safety

Check that all welding equipment, tools and materials are removed and that the area has been left clean and tidy and any walkways are clear. Welding processes involve the deposition of molten metal, often with appreciable spatter, and therefore it is essential to make sure that no slow smouldering process has been accidentally started.

◆ Ultrasonic testing

The repaired wheelburns need to be ultrasonically tested at the intervals given in table 4.

Table 4: Routine ultrasonic inspection frequencies (in months) (extracted from S1158)						
Track category	Full depth 070			Rail end 040		
	Open	Tube	Sub-surface	Open	Tube	Sub-surface
A	6	6	6	3	2	2
B	6	6	6	3	3	2
C	12	12	6	3	3	3
D (depot entrance only)	6	-	-	3	-	-

Full depth 070 - continuous rail test, using 0° and 70° probes (070 Rail Testing System), in accordance with test procedure U15.

Rail end 040 - rail end test, using 0° and 40° probes. In accordance with Network Rail's test procedures U1 and U2.

Depot entrance - boundary to be agreed in advance with The Track Engineer.

5.3 Summary

Though most modern trains give the generator instant indication of wheelslip, the problem of wheelburn will continue to present the Track Manager with maintenance and remedial work. This section has shown that the weld repair of this defect is straightforward and can enhance safety and reduce costs.



Where to find more information about repair of wheelburns

T0436 Weld repair of plain rails, switches and crossings

6 Maintenance welding of junctionwork

6.1 Introduction

The life of a rail in junctionwork is affected by the same features as plain line. Additionally, junctionwork experiences high battering forces from train wheels due to the discontinuity of the rails at crossings. Traffic flow affects the pattern of the wear - facing crossings normally suffer nose batter and on trailing crossings the wings wear more quickly. Loose blocks and bolts contribute to heavy impact and wear of the nose and wings. Switch rails suffer sidewear and damage, which (within limits) can be rectified by welding and/or grinding.

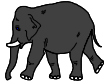
Points and crossings are the most expensive and heavily worked components of the track and the welding of these parts can significantly extend their life and ensures that the rail is maintained in a good condition to allow the safe passage of trains.

Failure to repair weld will lead to:

- ◆ heightened risk of derailment at facing switches, if the worn or damaged closed switch blade does not steer the wheel correctly
- ◆ continuing wear and batter on wings and nose which will loosen bolts and blocks
- ◆ heavy impact with the risk of cracked and broken rails and blocks, and derailments
- ◆ risk of wheel flanges striking blocks due to rail wear

- ◆ increased costs due to increased maintenance and premature renewal
- ◆ voids forming underneath the timbers, leading to poor track geometry
- ◆ broken fishplates
- ◆ the wheel flange taking the wrong path at the crossing, leading to derailment.

The techniques used for the repair welding of switches and crossings are discussed in section 4 of this handbook.



REMEMBER!

Repair welding of switches and crossings is a key safety element of junctionwork maintenance.

6.2 Switch types

Repair welding procedures are related to:

- ◆ the composition of the rail steel;
- ◆ the nominal rail profile;
- ◆ the machined profile;
- ◆ the distance from the switch tip (which determines the cross-sectional area of steel).

The Section Track Manager needs to know the above basic details of switch he is considering for repair so that he can plan the work.

Most switches are manufactured from grade R260 steel (formerly BS11 Grade A). This must be confirmed by reference to rolling marks in the rail web.

The nominal profiles of switches on LU are either:

- ◆ 95RBH;
- ◆ 56E1 (i.e. flat bottom full-depth); or
- ◆ 54E1A1 (i.e. flat-bottom shallow-depth).

The machined profiles are either straight-cut (95RBH only), undercut (95RBH only) or chamfered (56E1, 54E1A1 and some 95RBH).

T0436 places limits on the applicability of weld-repair to sideworn and damaged switch rails as follows:

Table 5: Details for the weld repair of sideworn and damaged switch blades by the MMA and FCAW processes		
	Sideworn	Damaged
Rail steel grades	R220, R260	R220, R260
Rail profiles	95RBH, 56E1, 54E1A1	95RBH, 56E1, 54E1A1
Switch design	Vertical/ inclined, chamfered, straight-cut, undercut	Vertical/ inclined, chamfered, straight-cut, undercut
Max. length of repair (from switch toe)	Switch type: A – C = 4.5m; D – F = 5.2m. In undercut switches – not within 300mm of the toe.	Switch type: A-H = 2m. In undercut switches – not within 300mm of the toe.
Max. thickness	10mm	20mm
Bead length	200mm maximum ¹	200mm max ²
1) Longer lengths can be repaired when using fully automatic welding equipment. An assessment of each proposed repair shall be carried out prior to welding taking place by the relevant Track Welding Manager; 2) Longer lengths can be repaired when using semi-automatic FCAW equipment. An assessment of each proposed repair shall be carried out prior to welding taking place by the relevant Track Welding Manager, particularly if a damaged switch blade is repaired in association with a side worn switch blade subjected to repair using fully-automatic welding equipment.		

6.3 Crossing types



As with switches, repair welding procedures are related to the composition of the rail steel. The Section Track Manager needs to know the basic details of the crossings to enable him to plan the work.

6.3.1 Cast common (acute)

These are the preferred type and are particularly suitable for heavily-trafficked locations. They are made with high-carbon austenitic manganese steel (there was at one time a low-carbon equivalent, but LU and Network Rail have standardised on the high-carbon steel and this is usually referred to simply as “AMS”). Cast common crossings are of three types:

Cast monobloc

In the monobloc crossing, the wing rails and crossing nose are formed as a single casting. They are cast from high carbon austenitic manganese steel (HCAMS) and can be identified by a cast number and from the manufacturer's trademark stamped or cast on the component. HCAMS is a non-magnetic material, and this property can be used to distinguish these components from other common rail materials. The abutting plain rails can be either fishplated or flash butt welded to the casting. In the latter there is an intermediate stainless steel insert and the area of the flash butt weld is termed the “tri-metal zone” or “TMZ”.

Cast centre block

In the cast centre block crossing the centre piece is cast in AMS, and four grade R260 running rail extensions are flash butt welded to the casting (using stainless steel inserts). For crossing angles up to and including 1 in 15, the wing rail extensions are in grade R260 and huck-bolted on to the casting. For angles flatter than 1 in 15, the wing extensions are part of the casting. For the same crossing angle the casting in a cast centre block crossing is shorter than that in a monobloc crossing.

Cast vee

In the cast vee crossing the vee is cast in AMS, the leg ends are flash butt welded to the vee at its splayed end (using stainless steel inserts) and the wings are bolted to the vee.

6.3.2 Semi-welded crossings

Semi-welded crossings are identified by the point and splice rails being welded to form the vee, the joint not being visible. The wing rails are attached by high-tensile bolts and blocks or multi-groove locking pins. The crossings are manufactured from R260 steel and incorporate permanent identification marks as illustrated in figure 1.

6.3.3 Fabricated crossings

Fabricated crossings are no longer a preferred type but many still exist in the LU network. They are identified by the vee being formed by joining the point and splice rails together with the joint being visible. The wing rails are attached by high-tensile bolts and blocks or MGL pins (on flat bottom crossings only). The crossings are usually manufactured from R260 steel, and incorporate permanent identification marks which are:

- ◆ brand marks on the rail web
- ◆ hot stamped marks on the rail web or side of the head
- ◆ paint marks (these are applied by the manufacturer at the rail end only, and should not be relied upon for identification of other than new rail).

Grade R350HT (formerly BS11 Grade B) rail is more difficult to weld. To avoid cracking, a higher preheat than that used for R260 rail is needed. The Track Engineer needs to be consulted for advice if any rails other than R260 are suspected.

6.4 Do I need to weld-repair?



S1158 gives inspection frequencies and guidance on what to look for when inspecting the track. It refers to the PM4 inspections which focus on junctionwork.

S1159 gives intervention thresholds for certain aspects of junctionwork condition, including wear and damage.

S1175 gives requirements for the frequency and method of detailed inspection of cast crossings and the minimum immediate actions to be taken in the event of defects being found.

S1176 gives requirements for the frequency and method of detailed inspection of facing switch blades and the minimum immediate actions to be taken in the event of defects being found.

Detailed weld-repair methods are given in T0436 and are not covered further in this edition of this handbook.

6.4.1 Switches

Visual inspection of the switches will indicate the main areas of wear or defects. Certain defects are derailment hazards and are listed in S1176 as follows:

Table 6: Derailment hazards at facing switches		
Hazard No.	Details	Tell tale signs
1	Sideworn stock rail associated with a little used switch rail	- The switch tip projects above the bottom of the sidewear scar - The switch tip has been struck by wheels - The switch tip has been deformed by wheels into the sideworn stock rail
2	Stock rail and switch rail both sideworn	- The switch rail may be more worn and display a flatter sidewear angle than the stock rail - The wheels have formed a ramp on the switch rail - Markings have been left by the wheel flange as it has begun to climb the switch rail and then slipped back
3	Stock rail headwear associated with a less headworn switch	The switch tip has been struck by wheels
4	Switch rail damage	- Lipping is present on the gauge face of the stock rail and/or the back edge of the switch rail - There is evidence of: * horizontal longitudinal cracking under lipping on the switch rail; * small pieces of metal starting to lift out of the switch rail; * numerous pieces having broken out of the switch rail; * hogged switch rails associated with lipped components
5	Switch rail with a sharp gauge corner profile	- Associated with austenitic manganese and mill heat treated rail steels, but may be present in newly-ground rails of all steel types. - Any profile forming a noticeable edge or faceted surface at the gauge corner - Dust / shavings of steel in proximity of switch - Bright marking indicating wheel contact with a sharp radius

If visual inspection (e.g. by the PM4 inspector) identifies any of these conditions the full detailed inspection shown in S1176 needs to be carried out. Depending on the assessed condition, the immediate remedial action usually comprises grinding to restore a satisfactory rail profile, weld repair or the replacement the switches (pending which a ban on facing moves may be required). The grinding and weld repair of switches are not covered in this edition of this handbook

6.4.2 Crossings

Visual inspection of crossings will indicate the main areas of wear or defects. Look for:

- ◆ wear and batter on the wings and nose. The wear and batter is normally present in the areas shown in figure 2. It can be seen and felt and the use of a straight edge is not necessary for this inspection

- ◆ the best time to arrange welding is when the wear is about 5mm. This amount of wear can be easily welded, lends itself to the best results and because of this is normally a long lasting sound repair. Plates 7 and 8 illustrate typical worn crossings
- ◆ surface flaking or breaking out of running surfaces on cast manganese crossings. These defects often indicate a poor casting. Plates 9 and 10 illustrate this defect
- ◆ old repair welding breaking out from nose or wings.

The above defects or wear indicate that repair welding is needed. Wear of less than 5mm is not generally worth welding as the increased impacts do not have a marked effect on the geometrical standards of the track.

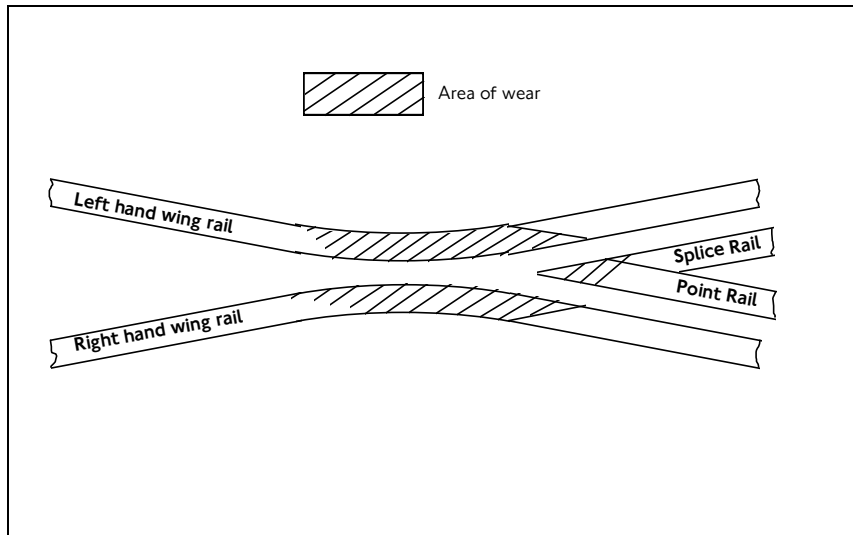


Fig. 2 Normal areas of wear on crossings



Plate 7 Typical worn common crossing

Note batter on nose. This crossing needs to be welded within 6 weeks.