Capacity for Rail

Towards an affordable, resilient, innovative and high-capacity European Railway System for 2030/2050

Operational failure modes of Switches and Crossings

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EXECUTIVE SUMMARY

The density of Switches and crossings (S&C) in most railway networks is estimated to be ~1 every km which equates to over 300,000 units within the networks of EU27 countries and the cost of maintenance of an S&C unit is believed to be equivalent to that for ~0.3km of plain line track. Further costs are incurred at renewals which, even at very modest rates of renewal, mount up to a very large figure. Thus the economic impact of S&C units on the maintenance and renewal budgets of railway authorities is very apparent. Hence any increase in the life span of this important infrastructure asset through better design or maintenance practices is considered highly desirable and is one of the primary objectives of this project.

The recently completed EU project, Innotrack, has emphasized the need to identify the major cost factors and use this knowledge as the drivers for essential improvements to design, installation, and maintenance practices. An understanding of the degradation mechanisms associated with S&C units is essential for the optimization of design and maintenance procedures to eliminate or minimize the impact of the causes of the life limiting degradation. This deliverable of a catalogue of defects that are encountered in S&C units is a contribution towards this objective.

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

Abbreviation / Acronyms	Description
AMS	Austenitic Manganese Steel
DB	Deutsche Bahn
NDT	Non Destructive Testing
RCF	Rolling Contact Fatigue
S&C	Switches & Crossings
SBB	Schweizerische Bundesbahnen
TCDD	Turkish state railways
TRV	Trafikverket
UoH	University of Huddersfield
VAE	Voestalpine VAE GmbH
VC	Vossloh Cogifer

TERMS AND DEFINITIONS

The European Standard EN13232-1 provides an accepted “terminology” for switch and crossing layouts. The present definitions set out the terms most generally used for the construction of switches and crossings.

Switch panel

That part of a turnout or layout ensuring the continuity of any one of two or three diverging tracks at the beginning of the divergence, consisting of two half sets of switches assembled together, usually with bearers.

Switch rail

Moveable machined rail, often of special section, but fixed and/or joined at the heel end to a rail to provide continuity of wheel support.

Stock rail

Fixed machined rail, ensuring the continuity on the main or diverging track with the switch in the open position.

Half-set of switches

Consists of one stock rail and its switch rail complete with small fittings.

Distance block

Part normally fixed to the stock rail ensuring the lateral support of its switch rail in the closed position.

Slide baseplate or chair

Part which supports and retains the stock rail and a flat surface upon which the foot of the switch rail slides.

Stretcher bar

Part joining the two switch rails of the same set of switches.

Switch and crossing baseplate

Load distributing baseplate placed between the bearer and the feet of two or more rails.

Closure panel

That part of a layout or turnout situated between the switch panel and the crossing panel consisting of rails with fastening system and usually on bearers.

Common crossing panel

That part of a turnout or layout ensuring the continuity of two intersecting routes by means of an intersection of opposite running edges and consisting of a common crossing, 2 outside rails, and 2 check rails complete with small fittings and assembled together, usually with bearers.

Common crossing

Arrangement ensuring the intersection of two opposite running edges of turnouts or diamond crossings and having one crossing vee and two wing rails.

- Movable crossings

  Crossings with a movable frog to eliminate the gap in the rail that normally occurs at the frog.

- Fixed crossings

  - Cast manganese crossings

    The complete central part of the crossing is cast as a manganese steel block.

  - built up crossings

    The point of the crossing is manufactured from rolled rail sections. Appropriate distance blocks are welded to the point. The wing rails are bolted to the point, using distance blocks.

Check or check rail

Special section bar ensuring (by guidance of the wheel) the safe passage of the axle opposite the neck gap of the common crossing.

TURNOUT COMPONENTS / SYSTEM

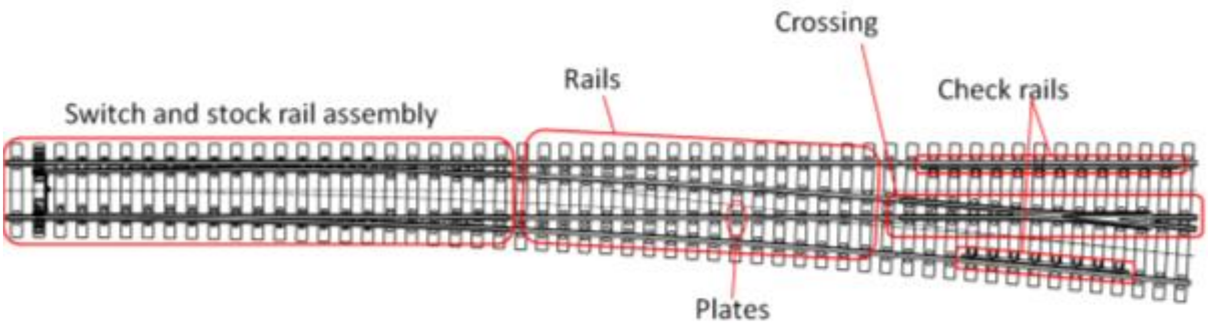


Figure 1: Switches and crossing layout

Table 1: Main components of S&C

Component	Function
Switch and stock rail assembly	Wheel support in vertical, lateral and longitudinal direction; wheel set guidance; route setting
Crossing	Wheel support in vertical, lateral and longitudinal direction; wheel set guidance; enabling free passage of the wheel flange through the crossing
Check rail	Wheel set guidance through the gap of the crossing; Support of the wheel flange in lateral direction
Running rail	Wheel support in vertical, lateral and longitudinal direction; wheel set guidance
Plates	Support of rails in vertical, lateral and longitudinal direction; fastening of rails
Fastening material	Support of lateral and longitudinal loads; elastic fastening of the rails and the plates
Driving and locking device	Controls the operation of turnouts. Moving switch blades, Locking switch blades in position, detection and verification of the position of switch blade.
Bearers	Take up of the vertical, lateral and longitudinal loads and transfer into the track bed

FAILURE LIST

The failure list is structured as shown below:

No.:	Reference number
Failure:	Name of failure
Component:	Name of the component, where the failure occurs
Characteristics:	Description of characteristics of the failure
Possible causes:	Description of the potential failure causes
Appearance:	Description of the appearance of the failure
Corrective/preventative measures:	Description of the corrective respectively the preventative measures to be undertaken to correct respectively to prevent such failures
Remarks:	Indication of supporting remarks

FAILURE SUMMARY

A matrix of the failures presented in this catalogue was produced highlighting which component and what root causes they are referring to. This is presented in a table form on the following two pages, while more details can be found in the complete catalogue in section 1. The purpose of this matrix is to allow a quick overview for the rest of the project partners (i.e. involved in the following up modelling work) to target specific root causes to be simulated and covering multiple types of defects in one go where possible. For example maintenance aspect related to non-optimal wheel and rail contact geometry can be found in a number of defects and simulation tools have been proved very efficient to take this into account. Optimization work in this area therefore has the potential to improve several types of defects modes.

Component and Root Cause \ Defect Number and Label	1.1.1 Spalling of stock rail in wheel transfer area	1.1.2 Lipping	1.1.3 Soft spots on running surface	1.1.4 Non-compliance of narrowest flangeway	1.1.5 Incorrect lateral attachment of switch rail	1.1.6 Broken Cast Items	1.2.1 Progressive Transverse Cracking	1.2.2 Shelling	1.2.3 Head Checks	1.2.4 Squats	1.2.5 Sub-surface Initiated Fatigue	1.2.6 Fatigue from Weld Repair	1.2.7 Fatigue from machining stress raisers	1.2.8 Foot failure from corrosion pit on base of foot	1.2.9 Wheel Burn	1.2.10 Short Pitch Corrugation	1.2.11 Long Pitch Corrugation	1.2.12 Imprints	1.2.13 Abrasive Wear	1.2.14 Uneven surface due to corrosion	1.3.9 Plastic deformation
All Rails in S&C							■	■	■	■	■	■	■	■	■	■	■	■	■	■	
• **Maintenance**								■	■	■	■	■									
Non-optimal contact geometry & contact band location → high Heartzian stresses & sub-surface crack development.											■										
Non-optimal contact geometry & contact band location → high stresses and near or sub-surface cracking that merge together to cause spalling. High linear density of cracks merging together to produce shelling								■													
Non-optimal contact geometry & contact band location → high stresses conducive to formation of rolling contact fatigue cracks									■												
Non-optimal contact geometry & contact band location → high stresses conducive to formation of squat defects										■											
Porosity or slag inclusions in weld repairs												■									
• **Manufacturing**							■														
Prescence of inclusions acting as initiation points for cracks							■														
• **Design & Manufacturing**													■								
Sharp stress raising locations from machining of rails in S&C													■								
• **Environmental**														■							
Corrosion pit at base of rail foot														■							
• **Operational**															■	■	■	■			
Damaged wheels, ballast imprints, foreign bodies																		■			
Non-optimal vehicle-track interaction leading to vehicle excitation to cause differential wear and plastic deformation of rail																■	■				
Wheel slip, particularly, during braking															■						
• **Track & Vehicle characteristics**																			■		
Leading to hard flange contact causing barasion of surfaces.																			■		
• **Environmental & Operational**																				■	
Corrosion of surface leading to uneven surface and accelerated roughness growth																				■	
Switch & Stock assembly	■	■	■	■	■																
• **Maintenance**	■	■			■																
Excessive lipping/burr on stock rail caused by high stresses					■																
Non-optimal contact geometry & contact band location → high stresses and near or sub surface cracking that merge together to cause spalling	■																				
Non-optimal contact geometry & contact band location → stresses above yield to cause plastic deformation		■																			
• **Manufacturing**			■																		
Incorrect heat treatment causing soft spots																					
• **Installation set-up**				■	■																
Incorrect adjustment of DLD				■																	
Incorrect adjustment of DLD & application of distance blocks					■																
• **Design**				■																	
Inapropriate S&C design				■																	
Anti creep device (ball&claw)						■															
• **Maintenance**						■															
Variable support stiffness						■															
• **Installation set-up**						■															
Incorrect stressing poor maintenance						■															

Component and Root Cause / Defect Number and Label	1.4.4 Casting defect leading to longitudinal crack	1.4.5 Transverse Crack on the crossing Nose	1.4.6 Tranverse crack on crossing bottom	1.4.7 Spalled weld deposit	1.4.8 Plastic deformation of crossing nose	1.4.9 Loosening of Screws of Crossings	1.4.10 Material breakout	1.4.11 Plastic defopmation of wing rail	1.4.12 Spalling of crossings	1.5.1 Excessive Wear	1.6.1 Contamination/Excessive Wear	1.6.2 Break of plates/check rail chair	1.6.3 Slide plate insert (pin) failure	1.7.1 Loosening/ loss of fastening elements	1.7.3 Broken bolts / screws	1.7.4 Cracked broken fishplates	1.8.1 Rotten/broken timber bearers	1.8.2 Cracked broken concrete bearers	1.8.3 Misaligned bearers	1.9.1 Breakage of stretcher bar joints	1.10.1 Large variation of track position in switch panel	1.10.2 Large variation of track position in crossing panel
Ballast bed																					■	■
• **Maintenance**																					■	
Dynamic forces on the whole structure leading to deformation in ballast or sub ballast layers																					■	
• **Installation & Maintenance**																						■
Dynamic forces on the whole structure leading to deformation in ballast or sub ballast layers. Uneven stiffness in the construction																						■
Bearers/sleepers																		■				
• **Maintenance**																		■				
Poor support conditions underneath and in vicinity of bearers leading to high dynamic loads. Can also be manufacturing flaw or poor installation																		■				
Bearers/sleepers Concrete																			■			
• **Maintenance**																			■			
Lack of ballast between bearers.																			■			
Bearers/sleepers Timber																	■					
• **Local environment**																	■					
deterioration of timber integrity because of poor local environment e.g. poor drainage. High dynamic load as a result of support deterioration																	■					
Cast Mn Crossing	■	■	■	■			■															
• **Maintenance**				■																		
Porosity or slag inclusions in weld reapirs				■																		
• **Manufacturing**	■																					
Casting defects - porosity/ inclusions	■																					
• **Design, Installation & Maintenance**		■	■																			
High dynamic forces, poor support condition and stress raising effect			■																			
High impact loads arising from non-optimum wheel-rail interface geometry and variable support		■																				
• **Manufacture**							■															
Casting defects (sub-surface porosity) , slag inclusions or porosity in weld repair							■															
Check Rails										■												
• **Track & Vehicle characteristics**										■												
Stiff bogies, narrow check rail gap, too high train speed and acceleration in diverging direction										■												
Fabricated crossings						■																
• **Design, Installation & Maintenance**						■																
Dynamic vibrations caused by variable stiffness, poor screw locking design						■																
Fastening elements in S&C														■								
• **Maintenance**														■								
High dynamic forces resulting from variable support & causing increased vibration														■								
Fishplates /Fish bolts																■						
• **Maintenance**																■						
High dynamic forces resulting from variable support. Incorrect fishplates, incorrect or loose fish bolts																■						
Fixed crossings					■			■	■													
• **Maintenance**								■	■													
Non-optimal contact geometry & contact band location → high stresses and near or sub surface cracking that merge together to cause spalling									■													
Non-optimal contact geometry & contact band location → stresses above yield to cause plastic deformation								■														
• **Design, Installation & Maintenance**					■																	
Incorrect check rail gauge, non-conformity of wheel and S&C design					■																	
Moveable crossing																						
• **Maintenance**																						
Non-optimal contact geometry & contact band location → stresses above yield to cause plastic deformation																						
Plates & check rail chair												■										
• **Maintenance**												■										
High dynamic forces resulting from variable support. incorrect adjustment												■										
Slide baseplates													■									
• **Maintenance**													■									
High dynamic forces resulting from variable support. incorrect adjustment of check rail gauge /flangeway clearance													■									
Slide plates/inserts/roller											■											
• **Maintenance**											■											
incorrect maintenance, adjustment											■											
Stretcher bar																				■		
• **Maintenance**																				■		
Poor maintenance leading to increased dynamic loads and vibration, excessive switch operation force, wheel flange back contact.																				■		
Various bolts, screws, & pins															■							
• **Maintenance**															■							
High dynamic loads with incorrect track support, poor track maintenance, incorrect torque applied															■							

1. FAILURE DESCRIPTION

1.1 Switch and stock rail assembly

No. and Failure	Component
1.1.1 Spalling of stock rail	Stock rail

Characteristics

This defect mainly occurs in the wheel transfer area of the switch/stock rail and shows cavities left by material having spalled out.

Cause

- High contact stresses leading to near surface crack initiation and subsequent merger to cause spalling. High stress can result from worn wheels (false flange) or non-optimal wheel transfer zone and narrow running bands.
- Wheel flange not matching together with design of wheel transfer zone
- Incorrect profile of wheel flange

Appearance

- In the wheel transfer area of the switch/stock rail

Corrective/Preventative Measures

- Deburring
- Grinding
- Replacement of switch and stock rail assembly
- (improved wheel profile management)

Failure detection

- by visual inspection

No. and Failure	Component
1.1.2 LIPPING	Switch and stock rail assembly

Characteristics

This defect mainly occurs in the wheel transfer area of the switch/stock rail and crossing nose/wing rail and appears as a plastically deformed lip. This defect can lead to material breakouts from the stock and switch rail and the crossing nose.

Possible Causes:

- Non-optimal wheel rail contact leading to high stresses that exceed the yield strength of the material and result in localised plastic deformation
- Wheel flange not matching together with design of wheel transfer zone
- Incorrect profile of wheel flange
- Poor maintenance (prevention of lip development through early deburring)

Appearance:

- Switch and stock rail assembly
- (Also moveable crossings)

Corrective/Preventative Measures:

- Deburring
- Replacement of switch and stock rail assembly (resp. moveable crossing)
- (Improved control of wheel profile & track geometry)

Failure detection:

- by visual inspection

No. and Failure	Component
1.1.3 SOFT SPOTS IN THE RUNNING SURFACE	Switch Rail

Characteristics:

This defect occurs mainly in the forged area of switch rails or in close proximity of welds of fixed or moveable crossings. It is characterised by a depression in the running surface caused by localised loss of hardness and strength as a result of the heating and cooling stages during forging.

Possible Causes

- Incorrect heat treatment of material during forging
- Incorrect welding procedure involving high preheat

Appearance

- Switch Rail (also fixed crossing and moveable crossings)

Corrective/Preventative Measures:

- Replacement of switch rail (resp. crossing)

Failure detection

- by visual inspection

No. and Failure	Component
1.1.4 NON-COMPLIANCE OF NARROWEST FLANGEWAY (RESIDUAL SWITCH OPENING)	Switch & stock rail assembly

Characteristics

Going below the limit of the narrowest flangeway can cause a touching of the switch rail by the wheel flange during passage of the vehicles. This defect can lead to whipping of the switch rail and hence (in worst case) to a break of the switch rail.

Possible Causes

- Incorrect adjustment of the driving and locking device
- Inadequate maintenance

Appearance

- Switch & stock rail assembly

Corrective/Preventative Measures:

- Correct adjustment of DLD system (if more than one DLD)
- Regular inspection & maintenance

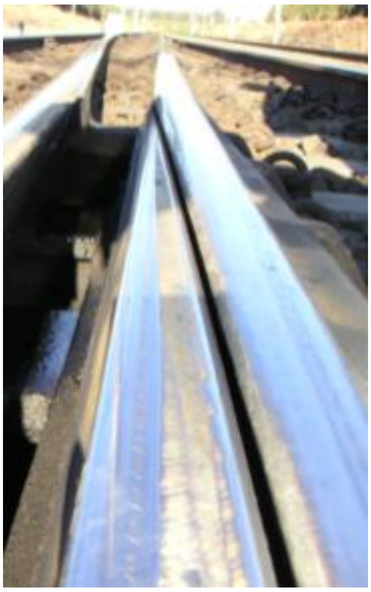
Failure detection

- by measurement of the narrowest flange way

No. and Failure	Component
1.1.5 INCORRECT LATERAL ATTACHMENT OF SWITCH RAIL	Switch & stock rail assembly

Characteristics

This defect is characterised by a small gap (incorrect lateral attachment) between switch and stock rail and respectively between the crossing nose and wing rail. The defect can cause high dynamic loads that lead to accelerated damage of S & C components.



Possible Causes:

- Incorrect adjustment of the driving and locking device
- Incorrect application of distance blocks
- Excessive lipping/burr on rails
- Incorrect switch rail straightening process

Appearance:

- Switch & stock rail assembly

Corrective/Preventative Measures:

- Correct adjustment of DLD system (Driving and locking device)
- Correct adaptation of distance blocks
- Deburring of rails

Failure detection:

- by visual inspection

No. and Failure	Component
1.1.6 BROKEN CAST ITEMS	Anti-Creep Device (Ball & Claw)

Characteristics:

This defect is characterised by a broken (normally the ball section) of a ball and claw type anti-creep device within switches.

This can lead to obstruction of rail vehicles, movement of the switch, incorrect alignment of the switch toes and subsequent point operation that in turn can cause detection failures.

Possible Causes

- Incorrect stressing methodology
- Poor Track Maintenance and incorrect setting upon installation

Appearance

- Broken component

Corrective/Preventative Measures

- Set switches correctly and replace broken component.

Failure detection

- by visual inspection

1.2 RAILS

No. and Failure	Component
1.2.1 PROGRESSIVE TRANSVERSE CRACKING	All rails in a S&C

Characteristics

This defect develops from a defect inside the rail head, from an internal horizontal crack or from deep shelling of the gauge corner (very unlikely). The appellation "kidney-shaped" is explained by the characteristic shape of this progressive crack. This serious defect can occur repeatedly in the same rail and result in large gaps in the event of multiple breaks (risk of derailment).

Possible Causes

- Rail manufacturing defect (mainly appears on older rails manufactured by ingot casting)
- High Hertzian shear stresses below surface (poor contact band conditions, wheel / rail matching)
- Lipping which is not removed

Appearance

- Develops from a defect inside the rail head (non-metallic inclusions or subsurface initiation) and is not limited to a certain zone.
- Can also develop from burrs/lipping from the outside.

Corrective/Preventative Measures:

- Temporary fishplating
- Replacement of rail

Failure detection

- Can be detected by ultrasonic testing

No. and Failure	Component
1.2.2 SHELLING	Rails

Characteristics

Shelling of the running surface: This defect is characterised by the appearance of a small crack in the outer face of the rail head, a few millimetres below the running surface. At a later stage, a piece of the metal may break or peel away.

Shelling of the gauge corner: The rails first show long dark spots randomly spaced out over the gauge corner of the merger of such cracks leading to localised loss of structural integrity and peeling /shelling of the surface material in the gauge corner which can sometimes be quite extensive.

Possible Causes

- High contact stresses leading to sub-surface or near surface cracks that merge together to cause localised loss of structural integrity that results in spalling/shelling of the material.
- Cracks due to Rolling Contact Fatigue (RCF), which are not removed before they merge.
- Previous weld repair was executed incorrectly.
- Crossings: High dynamic forces, lack of maintenance (grinding)

Appearance

- Shelling is generally not an isolated defect and often occurs in several zones. Gauge corner shelling occurs on the outside rails in curves.
- Fabricated crossings: fatigue damage due to dynamic loading conditions in the wheel transfer area.

Corrective/Preventative Measures

- Repair by resurfacing or repair welding.
- Replacement of rail

Failure detection

- Can be detected by ultrasonic testing

No. and Failure	Component
1.2.3 HEAD CHECKS	All rails in a S&C

Characteristics:

This typical RCF defect is characterised by small parallel cracks at the gauge corner. The distance between cracks varies depending on local conditions and the rail steel grade (normally smaller distances on head hardened rails). Depending on the wheel/rail contact condition the cracks are located with an angle of 35° to 70° (up to 90° for high traction) with reference to the longitudinal rail axis. In a first stage the cracks inside the rail head progress according to an angle of 10° to 15° and then they propagate in parallel to the running surface a few millimetres underneath the surface and end up again in the gauge corner where they may generate shelling/spalling. In certain cases the cracks grow transversally and may lead to a rail fracture.

Possible Causes:

- Rolling Contact Fatigue caused by poor contact band conditions, wheel / rail matching or vehicle / track characteristics

Appearance:

- Generally between 15mm to 25mm from the gauge corner of rails in a S&C and of moveable crossings

Corrective/Preventative Measures:

- Optimised rail-wheel contact with gauge corner relief (with care to conicity and wheel/rail interface)
- Optimised selection of rail steel grade for the conditions
- Preventive grinding
- Replacement of rail once cracks have turned down
- Limits for Head Checks, before they are growing down, should be defined (safety related)

Failure detection:

- Can be detected by visual and ultrasonic testing

No. and Failure	Component
1.2.4 SQUATS	All rails in a S&C

Characteristics

This RCF defect is visible on the running surface as a widening and a localised depression of the rail/wheel contact band, accompanied by a dark spot containing cracks with a circular arc or V-shape. The cracks propagate inside the head, at first at a shallow angle to the surface. Then, when they reach app. 3-5mm depth, the cracks propagate transversely and can lead to a break of the rail.

Squats on moveable crossings: This defect is characterised as longitudinal cracks on the surface of moveable crossings of high speed turnouts. The cracks propagate underneath the running surface and end up in the gauge corner (can result in spalling of the running surface) (Text from DB).

Possible Causes

- Multiple theories exist about the formation of squats with little universal agreement. Potential causes include high contact stresses, localised change of microstructure caused by wheel micro slip etc

Appearance

- On the running surface in the centre of the running band rail head axis and gauge corner
- Also often found on flash butt and aluminothermic welds.
- On the surface of moveable crossings of high speed turnouts.

Corrective/Preventative Measures

- Grinding
- Spot repair by resurfacing (if possible) or repair welding
- Replacement of rail

Failure detection

- Can be detected by visual inspection, ultrasonic testing or magnetic crack detection

No. and Failure	Component
1.2.5 SUB-SURFACE INITIATED FATIGUE	All rails in a S&C

Characteristics

There are no visible cracks on the surface that can be detected during track walking inspection or with eddy current testing. Ultrasonic testing will pick up such defects when they have grown to a large enough size as in the case of the classic “Tache Ovale” defects

Possible Causes

High Hertzian shear stresses below the running surface. Presence of oxide inclusions in old rail steels acted as stress raisers and initiated fatigue cracks that propagated and turned down to cause rapid fracture. However, sufficiently high stresses through non-optimal contact at gauge corner can cause sub-surface initiation of fatigue in modern clean steels

Appearance

Not visible at the surface but narrow running bands close to the gauge corner are indicative of the possibility of sub-surface initiated cracks

Corrective/Preventative Measures

- Optimised rail wheel contact with gauge corner relief to move the running band towards the centre of the rail head.
- Grinding
- Rail replacement once
- Monitoring of the location of running band is desirable to avoid narrow bands located too close to gauge corner

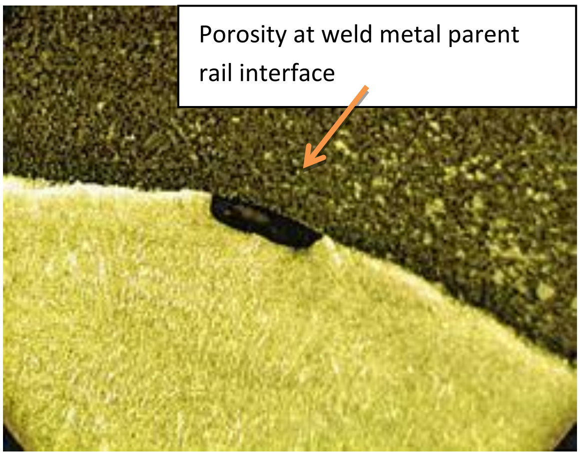
Failure detection

Ultrasonic testing can pick up sub-surface initiated RCF cracks only when they are large enough and that have or are approaching turn down.

No. and Failure	Component
1.2.6 FATIGUE FROM WELD REPAIR	All rails in a S&C

Characteristics

There are no visible cracks on the surface that can be detected during track walking inspection or with eddy current testing. Evidence of MMA weld repair can sometimes be detected on the running surface and can show plastic deformation but this is not a certain indication of the presence of sub-surface fatigue. Ultrasonic testing will pick up such defects when they have grown to a large enough size as in the case of the classic "Tache Ovale" defects.



Possible Causes

Presence of porosity at weld metal-parent rail interface acts as the fatigue initiation site under the high Hertzian shear stresses below the running surface. The presence of such defects is sufficient to initiate fatigue even under optimal rail-wheel contact.

Appearance

Not visible at the surface but sometimes plastic deformation of the weld repaired region can be indicative of sub-surface fatigue

Corrective/Preventative Measures:

- Rail replacement is the most likely remedial measure.
- The use of automatic weld repair techniques using flux cored wire ensures more controlled conditions to prevent porosity and slag inclusions and their use is recommended instead of MMA repair

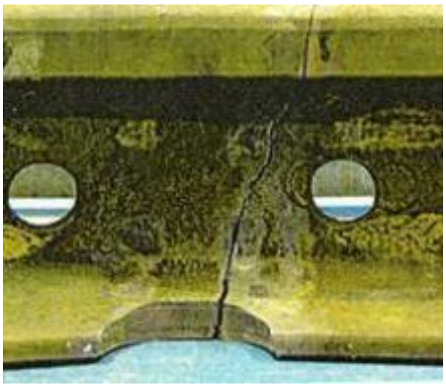
Failure detection

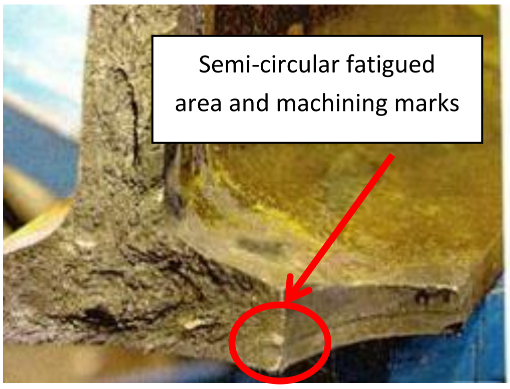
Traceability of weld repaired sections is desirable to enable more careful implementation of ultrasonic inspection.

No. and Failure	Component
1.2.7 FATIGUE FROM MACHINING STRESS RAISERS	All rails in a S&C

Characteristics

Such defects do not display any visible signs on the running surface until or close to the stage of fast brittle fracture. The nature of S&C design requires machining of the rail foot region that experiences the maximum tensile stresses and consequently the initiation of fatigue from any stress raisers arising either from the designed shape or through poor machining. The fatigued area is generally small and hence they are more difficult to detect unless directly in line with ultrasonic inspection.





Possible Causes

The foot of the rail experiences the maximum tensile stresses from the applied vehicle load and the presence of stress raisers, such as sharp machining marks, is sufficient to initiate fatigue. The critical defect size for fast fracture for the rail steels in use is quite small and hence the small fatigued area before brittle fracture of the whole section.

Appearance

Such defects are associated with stress raising sharp features such as machining marks or with corrosion on the underside of the rail foot. They can appear on all rails that have experienced machining. Early stage detection of such cracks through manual track inspection is not practical

Corrective/Preventative Measures

- Replacement is the most likely remedial measure.
- Desirable to avoid sharp edges in design.

Failure detection

- Closer inspection of machined components is also desirable.

No. and Failure	Component
1.2.8 TRANSVERSE FRACTURE FROM CORROSION PIT	All rails in a S&C

Characteristics

Corrosion on the base of the foot can have tiny sharp cracks that provide the site for fatigue initiation. They grow to a critical size under the cyclic loading but because of the outer fibre stresses experienced by the rail and the fracture toughness of the currently used pearlitic rail steel grades, fast brittle fracture results in a transverse break at a fatigued area no greater than a thumb nail.

Possible Causes

Environmental conditions leading to corrosion at the base foot and leading to fatigue initiation and subsequent fracture

Appearance

It is not practical to detect such defects during manual track inspections and they can often be missed by ultrasonic inspection car depending on the location and size of the fatigued area, Such failures can occur anywhere on the network and do not necessarily require very corrosive environment.

Corrective/Preventative Measures

Although barrier or galvanic coatings can prevent such failures, their wide spread use is not considered practical. Consideration should be given to protection in the rail seat area as the conditions between the pad and rail can cause corrosion.

Failure detection

Such small corrosion pits are not detectable by current NDT techniques and although it may be technically feasible to detect a thumb nail sized fatigued area by ultrasonic inspection, this is dependent on the fatigued area being directly underneath the web of the rail.

No. and Failure	Component
1.2.9 WHEEL BURN	All rails in a S&C

Characteristics

The slipping of a driving axle can cause an elliptical-shaped-self-hardened layer. This layer may disappear or develop - either horizontally where it soon degenerates into shelling or transversally in the head resulting in an internal crack which can lead to a break. Wheel burn defects are present on both rails of the track. A wheel burn can turn into a squat-type defect if not removed.

Possible Causes

Consequence of slipping of wheels on the rail during braking or accelerating giving rise to localised increase in temperature to very high levels that transforms the microstructure and characteristics of the rail steel.

Appearance

- On the running surface (of both rails) within the running band
-

Corrective/Preventative Measures

- Grinding
- Spot repair by resurfacing (if possible) or repair welding
- Replacement of rail
- Friction control

Failure detection

- by visual inspection

No. and Failure	Component
1.2.10 SHORT-PITCH CORRUGATION	All rails in a S&C

Characteristics

Short pitch corrugation is characterised by a pseudo periodical sequence of bright ridges and dark hollows on the running surface. The pitch generally varies between 20 and 100mm with a depth of 0,01 to 0,4mm.

Possible Causes

There is no universal consensus on the cause of short pitch corrugations, although it is generally accepted that it entails the combined effects of wear and plastic deformation. The contribution of discrete irregularities capable of excitation of the passing vehicle is also generally accepted.

Appearance

On the running surface (can occur on straight track) in curves with large radii or on low rail in small radii curves)

Corrective/Preventative Measures

- Grinding
- Use of harder steel grades

Failure detection

- by visual inspection
- by acceleration measurements

No. and Failure	Component
1.2.11 LONG-PITCH CORRUGATION	All rails in a S&C

Characteristics

Long pitch corrugation ("waves") is characterised by depressions in the running surface. The pitch generally varies between 30 and 300mm with a depth up to 1mm. With this type of corrugation, there is no difference in appearance between ridges and hollows.

Possible Causes

- No universal agreement on the root cause but (slipping of wheel is often cited as a key cause.)

Appearance

- On the running surface of the inside rail in curves with radii to 500m (partly to 800m)

Corrective/Preventative Measures

- Grinding
- Use of harder steel grades

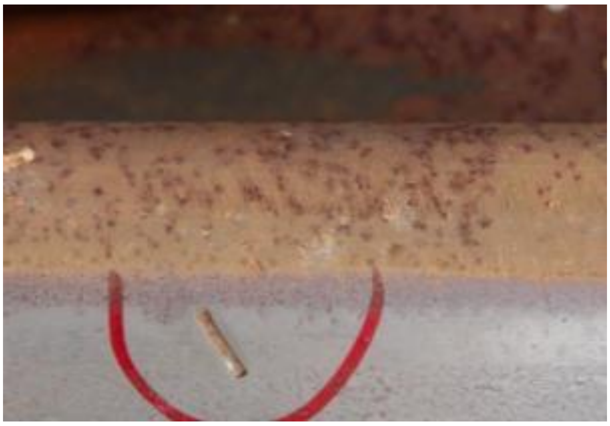
Failure detection

- by visual inspection
- by acoustic inspection
- by acceleration measurements

No. and Failure	Component
1.2.12 IMPRINTS	All rails in a S&C

Characteristics

This defect mainly occurs at regular intervals on several consecutive rails, sometimes over a considerable distance. When the imprint has a sharp profile, it can have a notch effect which can lead to cracks and finally in worst case to rail breaks.



Possible Causes

- Defect due to damaged wheels
- Ballast imprints
- Foreign obstacles

Appearance

- Periodically (depending on wheel size) on consecutive rails or randomly both rail lines

Corrective/Preventative Measures

- Spot repair (grinding, repair welding)
- Replacement of rail

Failure detection

- by visual inspection

No. and Failure	Component
1.2.13 ABRASIVE WEAR	All rails in a S & C

Characteristics

This defect mainly occurs in turnouts with small radii (< 500m). It is characterised by excessive wear of the outside rail in the diverging route. Excessive lateral wear can lead to critical gauge widening or to a rail fracture caused by weakening of the profile. This can be combined with metal flow on the switch tip.
The length and depth of such a defect should be categorized and limited to prevent derailment.


Possible Causes

- Small radii and switches mainly used in diverging route.
- High tensile forces on material.

Appearance

- Outside rail in the diverging route (mainly switch rail)

Corrective/Preventative Measures

- Keeping rail under observation, measuring wear
- Using of appropriate rail material (head special hardened)
- Replacement of rail. Grinding of metal flow.

Failure detection

- by visual inspection

1.3 Moveable crossings

1.3.1 Lipping for Moveable Crossings

See 1.1.2 – Lipping for Switch and stock rail assembly

1.3.2 soft spots in the running surface for Moveable Crossings

See 1.1.3 – Soft spots in the running surface for Switch and stock rail assembly

1.3.3 Incorrect lateral attachment of crossing nose for Moveable Crossings

See 1.1.5 – Incorrect lateral attachment of switch rail

1.3.4 Shelling for Moveable Crossings

See 1.2.2 – Shelling for Rails

1.3.5 Head Checks for Moveable Crossings

See 1.2.3 – Head Checks for Rails

1.3.6 Squats for Moveable Crossings

See 1.2.5 – Squats for Rails

1.3.7 Plastic deformation of wing rail for Moveable Crossings

See 1.4.10 – Plastic deformation of wing rail for fixed crossings

1.3.8 Spalling of crossings for Moveable Crossings

See 1.4.11 – Spalling of crossings for fixed crossings

No. and Failure	Component
1.3.9 Plastic deformation of the crossing nose	Crossing nose of moveable crossing

Characteristics

This defect is characterised by a depression in the running surface and lateral metal flow and subsequently burr on the crossing nose. This defect can lead to material breakouts of the running surface.

Possible Causes

- Non optimal rail-wheel contact in the wheel transfer zone that leads to increased lateral forces and the high resulting stresses that are above the yield strength of the material
- Wheel flange not matching together with design of wheel transfer zone
- Incorrect profile of wheel flange. Inadequate control of wheel profile

Appearance

- On crossing noses in the zone of the wheel transfer

Corrective/Preventative Measures:

- Deburring
- Resurfacing by build-up welding (if necessary)
- (correcting of wheel profile)

Failure detection:

- by visual inspection
- by geometry check

1.4 FIXED CROSSINGS

1.4.1 SOFT SPOTS IN THE RUNNING SURFACE FOR FIXED CROSSINGS

See 1.1.3 – Soft spots in the running surface

1.4.2 SHEELING FOR FIXED CROSSINGS

See 1.2.2 – Shelling for Rails

1.4.3 PLASTIC DEFORMATION OF THE CROSSING NOSE FOR FIXED CROSSINGS

See 1.3.9 – Plastic deformation of the crossing nose for moveable crossings

No. and Failure	Component
1.4.4 CASTING DEFECT LEADING TO CRACKING	Cast manganese crossing

Characteristics

Casting of large objects such as a crossing presents many challenges and, at times, can result in casting defects such as shrinkage cavities and porosity. Such defects are not visible to the surface and do not have a major impact on the life of the crossing if they are deep into the body of the casting. However, as the casting wears, such defects can become stress raisers leading to spalling and or failures. The photograph shows longitudinal cracking from a shrinkage cavity.

Possible Causes

- Manufacturing defect (shrinkage cavities and porosity) arising from casting preparations and conditions

Appearance

Such defects are not visible on the running surface but as the crossing wears, the defects become closer to the running surface and under the influence of the loading conditions that can propagate spalling or failure, at which stage they can be detected through manual inspections

Corrective/Preventative Measures

Weld repair implemented under consistent and controlled conditions after limited wear could prevent any casting defects coming under the influence of the loading conditions. However, further research is needed to establish the wear limits at which weld repair would be beneficial.

AMS crossings have given long lives in heavily used track and their wear rate is further reduced through explosive hardening

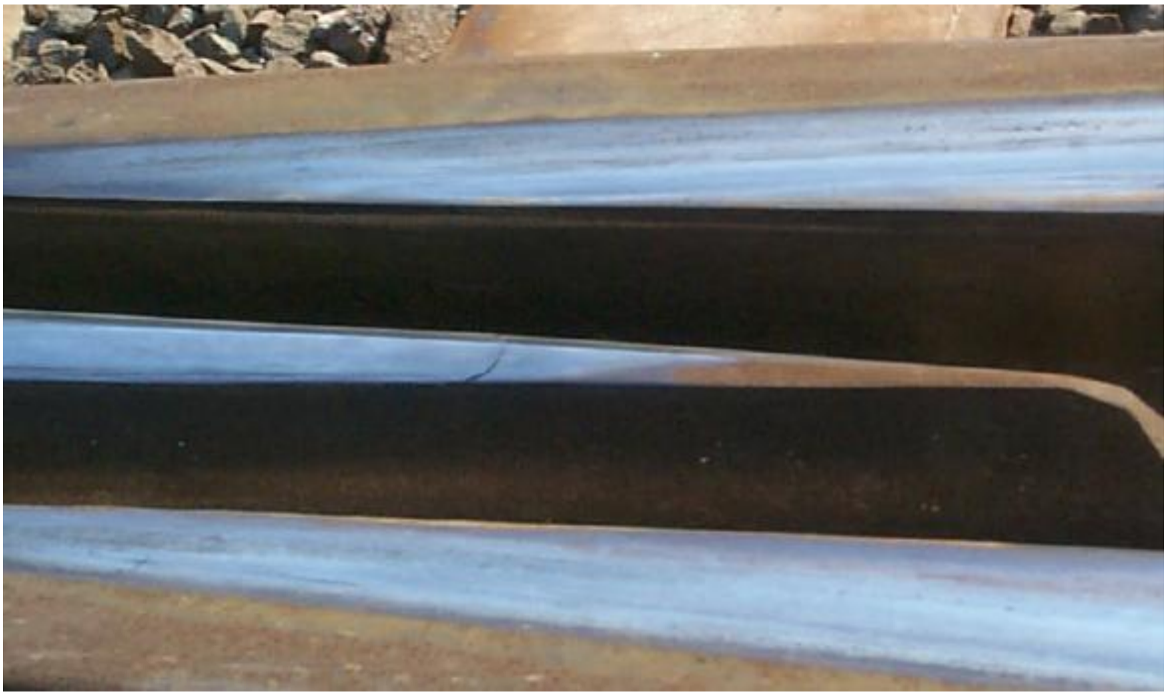
Failure detection

- by visual inspection

No. and Failure	Component
1.4.5 TRANSVERSE CRACK ON THE CROSSING NOSE	Cast manganese crossing

Characteristics

This crack is located in the front area of the crossing nose.



Possible Causes

- High vertical impact loading stresses on material due to wheel / crossing combination
- Wheel flange not matching together with design of wheel transfer zone
- Inadequate control of wheel profiles

Appearance

- In the front area of the crossing nose (wheel transfer area).

Corrective/Preventative Measures

- Easy to repair (Repair welding) but effectiveness could be limited when overheating of base material.

Failure detection

- by visual inspection

No. and Failure	Component
1.4.6 TRANSVERSE CRACK ON THE CROSSING BOTTOM	Cast manganese crossing

Characteristics

This crack is located in the rear zone of the crossing, from the wing rail end in the area of the closure rails.

Possible Causes

- High dynamic forces, poor support conditions, and mechanical damage at the base of the foot together with the stress raising effect at the edge of sleeper
- Manufacturing defect (casting porosities)
-

Appearance

- In the rear zone of the crossing, from the wing rail end in the area of the closure rails (mainly at the rear change of section surface).

Corrective/Preventative Measures

- Keeping crossing under observation
- Improved support to minimise deflection in the vicinity of crack
- Repair welding
- Replacement of the crossing when the critical crack length is reached.

Failure detection

- by visual inspection

No. and Failure	Component
1.4.7 SPALLED WELD DEPOSIT	Cast manganese crossing

Characteristics

The defect may not be visible on the running surface in the early stages of development and could be growing by fatigue initiated at a weld repair defect such as porosity or slag inclusion. Evidence of MMA weld repair can sometimes be detected on the running surface and presence of high plastic deformation of the weld metal could be indicative of internal fatigue development.

Possible Causes

Presence of porosity or inclusions at weld metal-parent material interface acts as the fatigue initiation site under the high Hertzian shear stresses below the running surface. The presence of such defects is sufficient to initiate fatigue even under optimal rail-wheel contact.

Appearance

May not be visible at the surface in early stages of development but sometimes plastic deformation of the weld repaired region can be indicative of sub-surface fatigue. Detectable only by close visual inspection

Corrective/Preventative Measures

- Cast crossing replacement is the most likely corrective measure but further weld repair restoration may be possible if detected early.
- Better control and automation of weld repair process is the most reliable preventative measure

Failure detection

No. and Failure	Component
1.4.8 Plastic Deformation of the crossing nose	Fixed crossing (cast manganese and built up)

Characteristics

This defect occurs only in turnouts with fixed crossings. It is characterised by bending and plastic yielding of the crossing because of the high lateral contact forces through non-optimal contact with the wheel.

Possible Causes

- Incorrect check rail gauge
- Non-conformity of boogies (wheels) with S & C design
- Incorrect geometry of previous weld repair (crossing nose too high, too thin or too much forward)

Appearance:

- Crossing nose of fixed crossings bent or broken off

Corrective/Preventative Measures:

- Check rail adjustment
- Repair of crossing nose (welding, grinding)
- Replacement of crossing

Failure detection

- By visual inspection

No. and Failure	Component
1.4.9 LOOSENING OF SCREWS OF CROSSINGS	Fabricated crossing

Characteristics

This defect is characterised by loosening of the screws of fixed built-up crossings. The defect can lead to further damage of S & C components.

Possible Causes

- Vibrations arising because of poor support conditions and high dynamic loads
- Inappropriate screw locking device

Appearance

- Fabricated crossings

Corrective/Preventative Measures

- Inspection procedures
- Refastening of screws

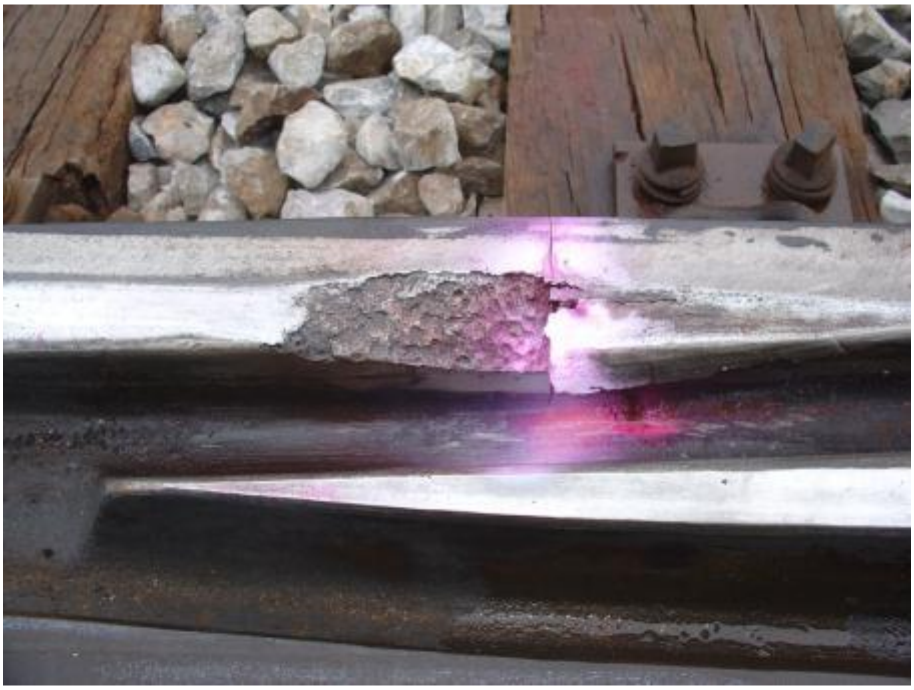
Failure detection

- by visual inspection

No. and Failure	Component
1.4.10 MATERIAL BREAK-OUTS ON MANGANESE CROSSINGS	Cast manganese crossings

Characteristics

This defect is characterised by breaking-out of material out of a Manganese frog.



Possible Causes

- High dynamic forces on material, fatigue damage Sub-surface porosity or casting defect that acts as the site of internal fatigue initiation – depending on the size of the defect, the sub-surface shear stresses arising from even optimal contact conditions can be sufficient to initiate and grow fatigue cracks.
- Incorrect previous repair welding (temperature too high).

Appearance

- Cast Manganese Crossings.

Corrective/Preventative Measures

- Repair welding of crossing
- Replacement of crossing.

Failure detection

No. and Failure	Component
1.4.11 Plastic deformation of wing rail	Fixed Crossings (cast manganese and built up)

Characteristics

This defect is characterised by a depression in the running surface and metal flow leading to the formation of burr on the inner side of the wing rail. This defect can lead to material breakouts and spalling (see also defect 1.4.11) of the running surface.

Possible Causes

- Stresses exceeding yield strength caused by high dynamic forces on material due to non-optimal wheel transfer zone
- Wheel flange not matching together with design of wheel transfer zone
- Inadequate control of wheel profile

Appearance

- On wing rails in the zone of the wheel transfer

Corrective/Preventative Measures

- Deburring
- Resurfacing by build-up welding (if necessary)
- Explosion depth hardening for cast manganese crossings

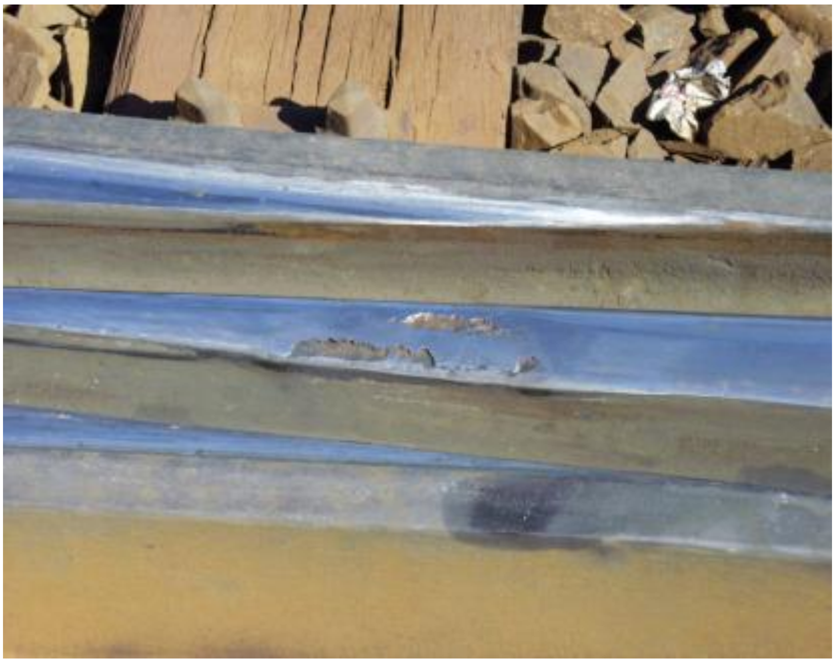
Failure detection

- Can be detected by visual inspection and geometry check

No. and Failure	Component
1.4.12 SPALLING OF CROSSINGS	Fixed Crossings (cast manganese and built up)

Characteristics

This defect mainly occurs in the wheel transfer area of the crossing nose/wing rail. In a pre-stadium the defect is characterised especially on the wing rail as a longitudinal crack below the running gauge.



Possible Causes

- High dynamic forces leading to sub-surface initiation of fatigue cracks and subsequent merging of cracks to cause spalling. High dynamic forces are likely to result from non-optimal wheel transfer zone and poor support conditions
- Wheel flange not matching together with design of wheel transfer zone
- Inadequate control of wheel profile

Appearance

- In the wheel transfer area of the crossing nose/wing rail

Corrective/Preventative Measures

- Deburring
- Repair welding mostly extensive (especially on the wing rail)
- Replacement of the crossing
- Adherence to the control limits on wheel profile

Failure detection

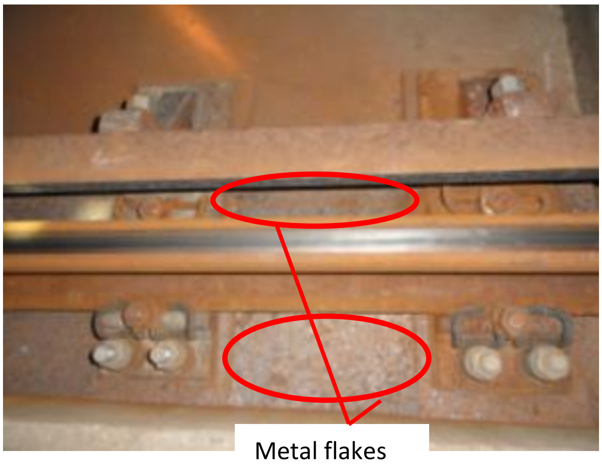
- by visual inspection

1.5 Check Rails

No. and Failure	Component
1.5.1 Excessive Wear on Check Rails	Check Rail

Characteristics

This defect is characterized by excessive wear on the thread bearing side surface of the check rail. A typical wear pattern can be seen together with fine metal flakes in the surrounding of the check rail. When this defect is not corrected, the check gauge is corrupted, which leads to damage on the crossing point (bent point, breaking out of point) and is safety critical.



Possible Causes

- Too stiff bogies with low self-steering properties.
- Too narrow check rail gap.
- Too high train speed in diverging direction.
- Accelerating train in diverging direction.

Appearance

- Check rails

Corrective/Preventative Measures

- Re-adjust check gauge with shims.
- Replace check rail.
- Choose check rail of higher steel grade.
- Vehicle maintenance

Failure detection

1.6 Plates

No. and Failure	Component
1.6.1 Contamination / Excessive wear of slide plates/sliding inserts or roller systems	Slide plates, sliding inserts, roller systems of switch & stock rail assembly respectively moveable crossings

Characteristics

This defect is characterised by contamination or excessive wear of slide plates respectively the sliding inserts or roller systems. The defect may lead to setting problems of S & C.

Possible Causes

- Incorrect maintenance
- Incorrect adjustment of roller systems

Appearance

- Slide plates

Corrective/Preventative Measures

- Cleaning of slide surface
- Proper lubrication respectively adjustment of roller systems
- Replacement of sliding inserts / slide plates

Failure detection

- by visual inspection

No. and Failure	Component
1.6.2 BREAK OF PLATES / CHECK RAIL CHAIR	Plate, check rail chair

Characteristics

This defect is characterised by a structural break of baseplates (common baseplates/ slide baseplates / check rail supports).

The defect may lead to failure propagation (high tensile forces on adjacent components) and can lead to a critical failure in the case of multi-failures.

Possible Causes

- High dynamic forces on material due to insufficient support stiffness
- Incorrect adjustment of check rail gauge (flangeway clearance)

Appearance

- Broken plates and chairs

Corrective/Preventative Measures

- Adjustment of check rail gauge
- Redundancy of elements
- Replacement of components

Failure detection

- by visual inspection

No. and Failure	Component
1.6.3 SLITE PLATE INSERT (PIN) FAILURE	Slide baseplates

Characteristics

This defect is characterised by a loosening or breaking of the retaining pins on slide baseplate inserts.

The defect may lead to failure of switch operation and subsequently detection of point operation equipment.

Possible Causes

- High dynamic forces on material
- Inappropriate design for local conditions
- Incorrect adjustment of check rail gauge (flangeway clearance)

Appearance

- Broken / missing retaining pins
- Slide insert loose or missing

Corrective/Preventative Measures

- Replacement of components

Failure detection

- by visual inspection

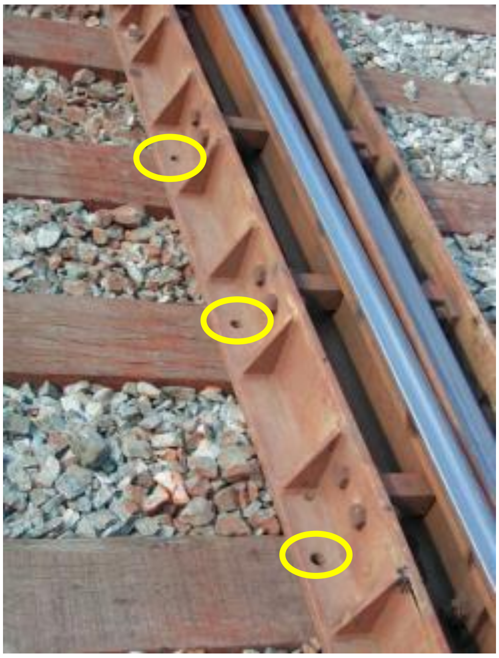
1.7 Fastening material

No. and Failure	Component
1.7.1 BREAK/LOOSENING OF FASTENING ELEMENTS	Fastening elements in a S&C

Characteristics

This defect is characterised by a loosening/loss of fastening elements in S&Cs.

The defect may subject other adjacent components to increased stresses and vibration and eventually to their failure.



Possible Causes

- High dynamic forces/vibrations on material due to insufficient support stiffness
- Incorrect fastening

Appearance

- All fastening elements in a S & C

Corrective/Preventative Measures

- Inspection procedures
- Redundancy of fastening elements
- Refastening of elements

Failure detection

- by visual inspection

No. and Failure	Component
1.7.2 BROKEN BOLTS / SCREWS	Crossing Bolts / Switch Bolts / Multiple Groove Locking Pins

Characteristics

This defect is characterised by a by Broken Bolts in the switch and crossing assemblies

This can lead to baseplates and blocks becoming loose and obstructing either rail vehicles or the movement of the switch

- Heel block bolts
- Crossing Bolts
- Fishbolts
- Switch slide bolts
- Switch Spacer bolts
- Check Rail Bolts
- Switch Chair screws

Possible Causes

- High dynamic forces/vibrations on material due to insufficient support stiffness
- Poor track maintenance, incorrect torque applied to nuts
- Localised environmental conditions leading to corrosion of components

Appearance

- Broken Bolts, missing nuts and washers
- Loose / missing cast items

Corrective/Preventative Measures

- Replace broken bolts and associated failed cast items
- Regular maintenance and application of correct torque

Failure detection

- by visual inspection

No. and Failure	Component
1.7.3 BROKEN BOLTS / SCREWS	Crossing Bolts / Switch Bolts / Multiple Groove Locking Pins

Characteristics

This defect is characterised by a crack or break in the Fishplate which can lead to a critical failure of the rail joint.

This can apply to both standard and insulated (pictured) fishplates. Where the issue relates to insulated fishplates this can lead to track circuit failures.

Possible Causes

- High Dynamic loads and incorrect track support at joints
- Inadequate maintenance to tighten loose bolts
- Use of incorrect fishplate type for specific applications

Appearance

- Crack / Break through fishplate
- Missing nuts on bolts

Corrective/Preventative Measures

- Replace defective fishplate,
- Correct greasing of fishplates

Failure detection

- by visual inspection

1.8 BEARERS

No. and Failure	Component
1.8.1 ROTEN / BROKEN TIMBER BEARERS	Timber bearers

Characteristics

This defect is characterised by a defect in the timber bearer which may lead to inability of the bearer to support the track system.

It can lead to baseplate screws becoming loose and premature failure of cast baseplates and subsequent failure of other system components.

Switch detection can also be affected as backdrive mounting plates become loose.


Possible Causes

- High dynamic loads
- Deterioration of timber integrity because of poor local environment e.g. poor drainage.
- Incorrect track drainage
- Poor Track Maintenance
- Aging

Appearance

- Loose Baseplate Screws
- Missing sections of timber

Corrective/Preventative Measures

- Replace defective bearer

Failure detection

- by visual inspection

No. and Failure	Component
1.8.2 CRACKED / BROKEN CONCRETE BEARERS	Concrete bearers

Characteristics

This defect is characterised by a defect in the concrete bearer which may lead to inability of the bearer to support the track system. It can lead to baseplate screws becoming loose and premature failure of cast baseplates and subsequent failure of other system components.

Switch detection can also be affected.

Possible Causes

- High dynamic loads
- Inconsistent support conditions in vicinity of sleepers/bearers
- Incorrect mix design of concrete or poor installation of components
- Foreign obstacle in screw holes when tightening (before installation or during maintenance)
- Poor Track Maintenance

Appearance

- Loose Baseplate Screws
- Missing sections of concrete, exposed pre-stressing wires, longitudinal cracks

Corrective/Preventative Measures

- Replace defective bearer
- Use of steel reinforcements around dowels/fastening inserts

Failure detection

- by visual inspection

No. and Failure	Component
1.8.3 MISALIGNED BEARERS	Concrete bearers / sleepers

Characteristics

The bearer is moved longitudinal either by forces in the ballast layer or at tamping operation.

The distance between the baseplates changes and therefore the rail is no longer supported in a correct way. It will lead to higher stresses in some parts of the rail and higher dynamic loads of the whole system.

Switch rods may also come in conflict with the bearer leading to difficulties to move the switch blades.

Pictures from Trafikverket

Possible Causes

- Longitudinal loads in the ballast
- S&C moving longitudinal
- Lack of ballast between bearer
- Incorrect Track Maintenance

Appearance

- Misaligned bearer
- Bearer in contact with rods

Corrective/Preventative Measures

- Reposition bearer

Failure detection

- by visual inspection

1.9 DRIVING AND LOCKING DEVICE

No. and Failure	Component
1.9.1 BREAKAGE OF STRETCHER BAR JOINT	Stretcher bar

Characteristics

This defect is characterised by a breakage of the stretcher bar. This can occur in one or a combination of areas depending on the design of the stretcher bar and frequency of use.

In addition to failures in the actual bar (for example 'goose neck' and 'ear' failures) it can be resulting from missing or loose bolts.

This can lead to critical failures of the S&C system.

Possible Causes

- Poor maintenance leading to increased dynamic loads and vibrations
- Excessive switch operation forces
- Wheel flange back contact

Appearance

- Cracks evident in Stretcher bars components
- Loose / missing parts

Corrective/Preventative Measures

- Replace defective bar

Failure detection

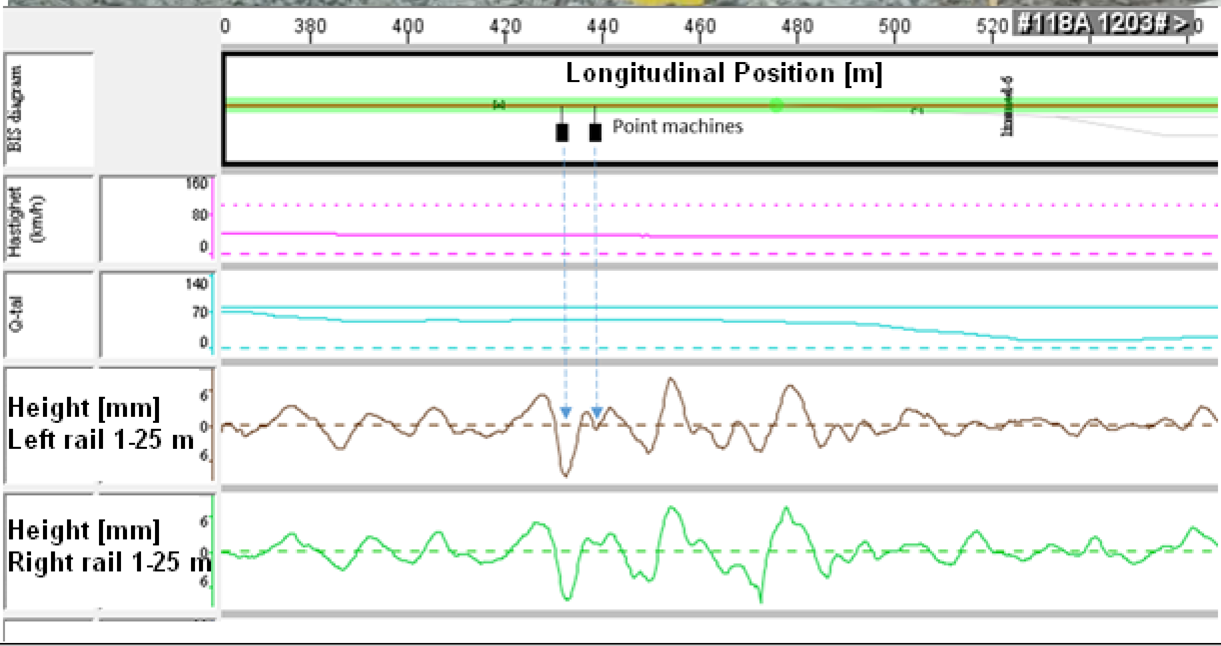
- by visual inspection

1.10 Ballast bed

No. and Failure	Component
1.10.1 BREAKAGE OF STRETCHER BAR JOINT	Ballast bed

Characteristics

This defect occurs after certain traffic load and depends on uneven bed modulus and imperfect tamping due to difficulties to tamp for instance where the point machine are and at positions with stretcher bars.



Possible Causes

- Dynamic forces on the whole structure leading to deformation in ballast or sub ballast layers

Appearance

- In the switch panel

Corrective/Preventative Measures

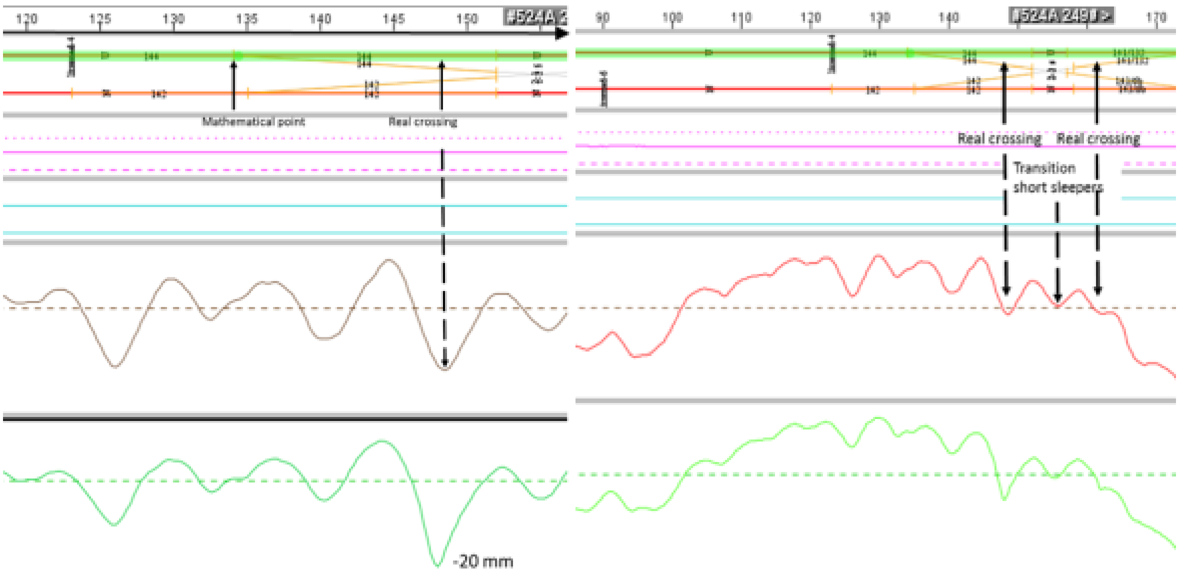
- Tamping of whole switch or spot tamping

Failure detection

No. and Failure	Component
1.10.2 LARGE VARIATION OF TRACK POSITION IN CROSSING PANEL	Ballast bed

Characteristics

This defect occurs after certain traffic load and depends on uneven bed modulus and imperfect tamping due to difficulties to tamp where the sleepers are long. The dynamic forces are higher in this area as the wheel transfer between wing rail and stock rail induce dynamic forces. The larger area of the longer sleepers also typically results that they do not sink as fast as the ordinary sleepers behind the crossing panel, leading to height differences in the transition.



In the figure is shown short wave filtering (1-25 m) and unfiltered (1-150 m). Short wave is most important for the dynamic forces. Longer wavelengths show the difficulties of tamping without good height references. In this case the left S&C is tamped more often so it is higher than the right one.

Possible Causes

- Dynamic forces on the whole structure leading to deformation in ballast or sub ballast layers. Uneven stiffness in the construction

Appearance

- In the crossing panel

Corrective/Preventative Measures

- Tamping of whole switch, replacement of bearers in crossing area and/or ballast cleaning

Failure detection

REFERENCES

[1] UIC 712 R, Rail defects; 5^{th} Edition, (in preparation for 2016).

[2] EN 13232-1, Railway applications – Track – Switches and crossings, Part 1: Definitions, 2004