

# WHY RAILS CRACK

Metal fatigue in rails was recently highlighted as the likely cause of the Hatfield train crash. Four key members of the international research group WRISA reveal how the interactions between wheels and track led to the failure, and explains how the rail industry will need to deal with this phenomenon.

The Hatfield train crash in October 2000 brought 'gauge corner cracking' to the attention of the British railway industry and to the travelling public. An intercity train left the track because of a fracture in the high or outer rail of a 1,500 metre radius curve. What was unusual about the break was the apparent disintegration of the rail itself. Subsequent investigations concluded that there were numerous

cracks in the contact area between rail and wheel, the 'running band'. When one of these cracks penetrated to the base of the rail, approximately 30 m of rail failed catastrophically.

This prompted Railtrack, Network Rail's predecessor as the track maintenance and management company, to instigate a rigorous inspection programme. This revealed so much gauge corner cracking

on the rail network that the company imposed temporary speed restrictions and emergency rail replacements, resulting in many delays and cancellations. And yet before the accident few people had even heard of gauge corner cracking, and no one knew why it had suddenly occurred at Hatfield. Why had gauge corner cracking emerged so dramatically as a major problem? The search began for the cause.

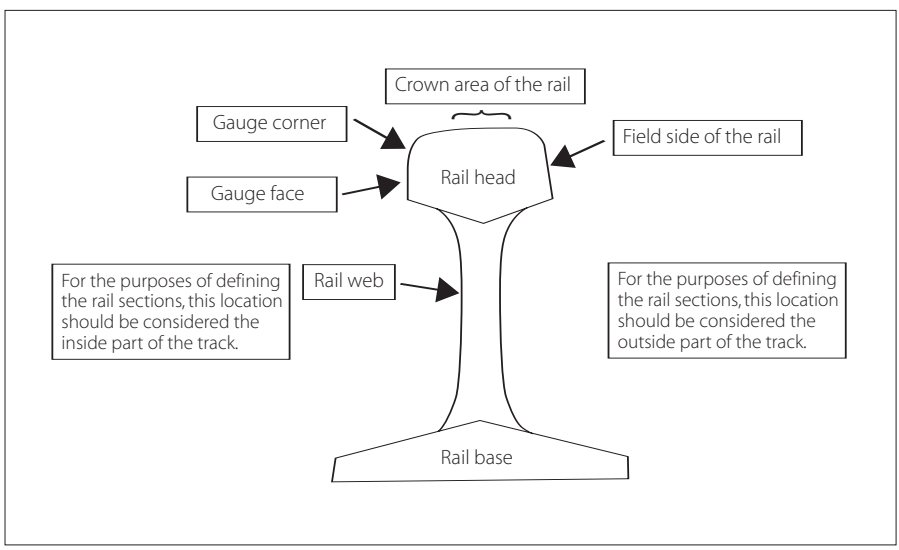


Figure 1:

The anatomy of a rail. The gauge face is between the two rails that comprise the track, and the contact patch is an area about the size of a five pence coin where wheel and rail are in contact.

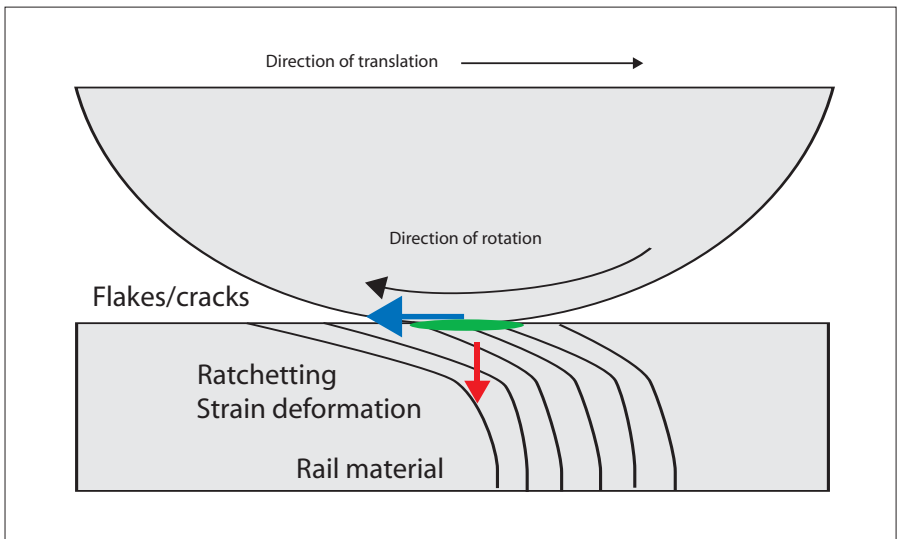


Figure 2:

Contact patch pressure and forces causing surface elastic deformation of the rail microstructure, leading to RCF.

Green figure: Contact patch  
Blue arrow: Longitudinal shear force  
Red arrow: Normal force

### ROLLING CONTACT FATIGUE

'Gauge corner cracking' (cracks on the gauge corner) and 'head checking' (cracks on the head of the rail) are both examples of the more general phenomenon of rolling contact fatigue (RCF) which occurs in bodies in rolling contact. Such bodies can damage one another in various ways depending upon the severity of the contact pressure and the shear or 'tearing' forces in the area where the bodies come into contact. For most trains in Britain this 'contact patch' is about the size of a five pence coin, and the behaviour in this contact patch creates the forces between the wheel and rail that lead to RCF.

Rolling contact fatigue can cause damage in the form of surface cracks by

wearing away the rail, or through plastic flow of the materials. In the initial stages, RCF creates short cracks that grow at a shallow angle, but these can sometimes grow from a shallow to a steep angle. This 'turndown' tends to occur when cracks reach 30 mm in length, and at this stage the probability of rail fracture becomes much higher.

The Hatfield accident prompted significant research into rolling contact fatigue on the British railway system and led to the establishment of the Wheel Rail Interface Systems Authority (WRISA) to bring the British rail industry together to consider the issue. WRISA undertook an extensive series of tests – both in the laboratory and in the field – to investigate the causes of rail cracking and to come up with

recommendations for the design and maintenance of suspension, rail and track.

Initially the railhead cracks at Hatfield were described as gauge corner cracking, which occurs on the gauge corner itself; however, the picture turned out to be more complex. Most cracking could be more appropriately described as 'head checking', as the cracks were found more towards the centre of the rails, usually 15 to 25 mm from the gauge face (Figure 3).

### THE THREE RCF MODES

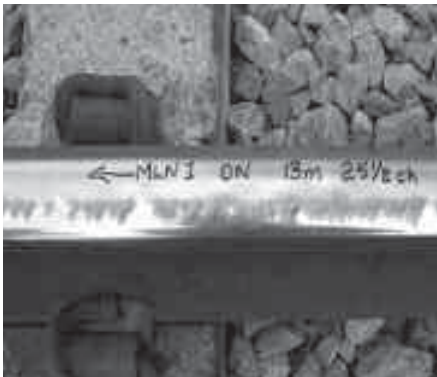
It was first thought that quasi-steady-state wheel-rail contact forces alone caused rolling contact fatigue in the form of head checking and gauge corner cracking. We now know that this is not the case. Intensive

Figure 3 (below):

Two different types of rail cracking caused by rolling contact fatigue: **gauge corner cracking** (top) and **head checking** (bottom)



An example of gauge corner cracking on a 900m curve high rail



An example of head checking on a 1300m curve



Investigators stand near the remains of the GNER high-speed train that derailed at Hatfield on 17 October 2000  
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investigations from late 2000 through to 2003 have revealed at least three separate modes of RCF initiation and growth on British railways: steady state, bi-stable and convergent motion. The locations of RCF cracks on the rail head fit with the dynamic wheel–rail interface behaviour expected in these three modes.

**Steady-state mode** is thought to occur in tighter curves with radii of 1,200 m and less, and has traditionally been seen as producing rolling contact fatigue. It is the mode that best describes gauge corner cracking and head checking in curves.

**Bi-stable contact mode** describes rolling contact fatigue that occurs when the

wheel–rail interface operates in a region of instability in which small changes in lateral shifts in the wheels generate large changes in rolling radius. This mode is thought to occur in curves with radii of 1,200 to 2,000 m, although the same behaviour may happen on tighter and shallower curves.

**Convergent-motion mode** describes rolling contact fatigue that occurs when the track appears – due to alignment changes – to slip sideways in relation to the wheel, and the wheel flange converges upon the rail's gauge face, even though the wheel flange may not to come into contact with the gauge face. This behaviour is thought to occur in moderate curves with radii of 2,000 m or more, and in straight track. Again, this

behaviour may also happen on tighter curves where we normally expect bi-stable mode RCF.

Field investigations indicate that convergent motion is probably the main cause of rolling contact fatigue in trackwork other than plain track and switches and crossings. On the gauge corner of the tight radius portion of switch blades, steady-state curving forces are likely to cause RCF. But the convergent motion mode probably affects the rail components at the switch transitions, switch entry and trailing points, stock and closure rails, and crossings.

## EXCESS FORCE

In all cases in the British system, rolling contact fatigue is due to excess wheel–rail forces. These are primarily caused by the axle shifting relative to the rail too far to one side or the other. This is true on curves, straight track or switches and crossings (S&C). In tight curves, the mechanism tends to be steady state, while the mechanism is transient in S&C and moderate curves and straight track.

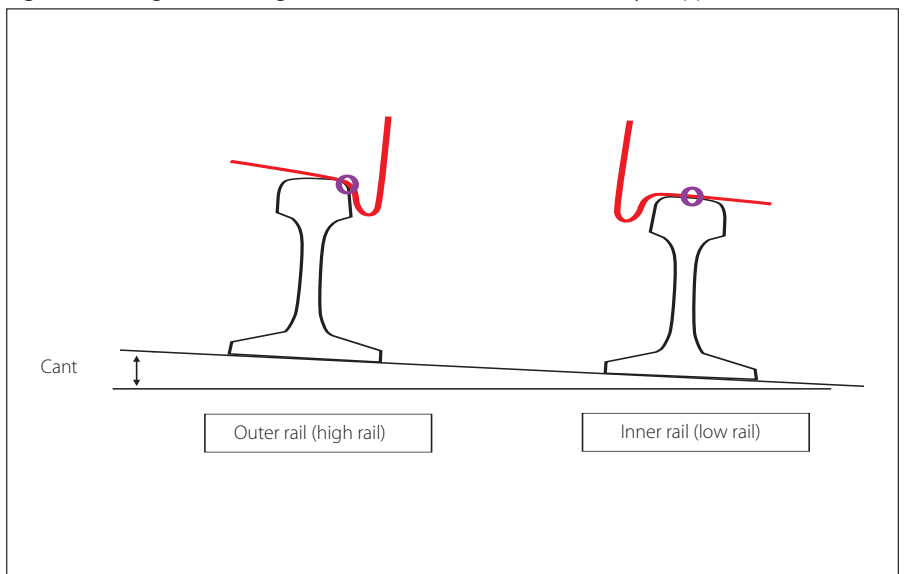
We now know that in the British rail system most rolling contact fatigue occurs on curves and almost always happens on the outer high rail (Figure 4). We also know that RCF is most likely on curves with a radius of approximately 1,500 m. Where RCF happens on straight track it is usually associated with switches and crossings. In shallow curves, where we expect wheel-to-rail contact to be on the gauge shoulder of the rail, the RCF occurs as head checks rather than the gauge face. In tight curves, where we expect the contact between wheel and rail to be near the gauge corner, the cracking appears as gauge corner cracking.

We can also see variations in the types of cracking that depend on the suspension of the vehicles passing over the rails. For example, wheels of bogies with stiff suspensions contact the rail near the gauge corner while softer suspensions contact the rail higher on the railhead.

## VEHICLE SUSPENSION

Research by the British railway industry shows that wheel wear, track alignment, and bogie primary yaw stiffness – essentially the horizontal rotational stiffness between axles on a bogie – are all important factors in the initiation and growth of rolling contact fatigue. For example, a study on the London–Tilbury–Southend line identified a relationship between the primary stiffness of a bogie and the probability of RCF as

Figure 4: Rolling contact fatigue occurs on curves and almost always happens on the outer rail



conformal wheel wear increases. The potential increase in RCF with bogie yaw stiffness can be attributed to the higher forces required to deflect the suspension as the train travels around the curve. Wheels with worn tread had the most pronounced effect.

So if bogie stiffness plays a key role in initiating rolling contact fatigue, why don't all bogies have soft primary suspensions? This would reduce curving forces, leading to less curve wear and less RCF. Unfortunately, high bogie stiffness is essential for stability at speed on straight track. Modern rolling stock must be stable at high speed to satisfy the demands of today's travelling public. In general, bogie stiffness must increase proportionately to the square of the operational speed to avoid 'hunting', the propensity for the bogie to oscillate from side to side on straight track.

However, the stiffness of many vehicles in the British fleet may be much higher than necessary. Although engineering and financial issues such as ease of construction

and maintenance may have influenced the designs, they are not optimised for the wheel–rail interface and result in bogies prone to both rolling contact fatigue and wear. Investigations continue and will expand from those solely considering RCF on rails. Some newer vehicles introduced to the British system are starting to exhibit RCF on wheels, which is perceived to be complementary to the RCF on the rails.

## THE WRISA FINDINGS

Research by WRISA suggests that suppliers and those specifying trains should reassess the design philosophies around the high stiffness currently used for primary suspension to determine if softer suspension will serve vehicle performance needs and lead to a more finely tuned vehicle-track system interface. We can also draw a number of conclusions from the existence of the distinct RCF initiation modes and from the pervasive influence of profile shape:

*Rolling contact fatigue can happen even when vehicles and tracks are well within current safety standards. Railway Group Standards ignore many important factors for the optimised operation of the railway system.*

- Track and vehicle conditions that are well within the current Railway Group Standards established by the Rail Safety and Standards Board can still create RCF.
- Distinct conditions contribute to separate RCF initiation modes, and there are specific remedies to the initiation and propagation of RCF.
- Track alignment and higher wheel wear may remain within standards but still result in increased RCF.
- Operational demands may require increased bogie yaw stiffness but this will generally increase the probability of RCF.
- Reduced intervals between wheel turning may have cost benefits to operators but the resultant increase in conformality between the wheel and rail profiles can increase the probability of RCF. (The industry struggles to define 'conformality'. If the wheel and rail are shaped so that they touch over a large stretch of surface across the rail head then they are 'conformal'.)

In the light of these findings, the British railway industry is beginning to accept that it has to manage and control both sides of the wheel-rail interface to tackle rolling contact fatigue on the network.

To control **steady-state mode RCF** in tight curves, the control measures for track are grinding to a profile that prevents RCF and provides relief to the gauge corner and gauge shoulder of the rail, along with gauge-face lubrication to minimise wear and changes to the wheel-rail profiles. Lubrication can also suppress gauge corner cracking if some lubricant travels up onto the gauge corner of the rail. The control measures for vehicles are to reduce primary suspension stiffness to allow better curving performance, and to reduce the conformality between the wheel flange root and gauge shoulder and corner.

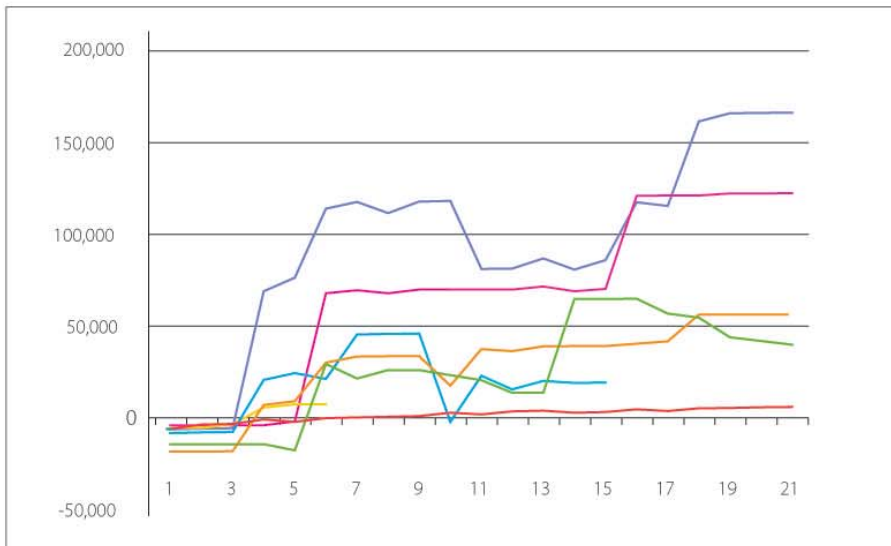
The measures needed to control **bi-stable mode RCF** in moderate curves are to grind the rail to provide gauge corner relief and reduce the conformality between the wheel flange root and the rail gauge shoulder and corner, and to improve track alignment. Grinding will reduce the wheel-rail conicity (conic nature) and the sensitivity to small changes in relative positions of wheel and rail. Improving track alignment includes correcting tight gauge, excessive twists, and, in particular, short wavelength lateral misalignments with rates of change below the kinematic wavelength of the bogies. The control measure for vehicles is to lower conformality between the wheel flange root and rail gauge shoulder and corner.

For track, the primary control measures to control **convergent motion mode RCF** are to improve track alignment and to control the wheel-rail profiles through grinding. As with bi-stable mode, the control measure for vehicles is to lower conformality between the wheel flange root and rail gauge shoulder and corner.

## ESTIMATING THE COST

Whatever solutions the industry chooses, they must deliver better value for the British railway industry. WRISA's Great Western project analysed a number of RCF sites by comparing two maintenance schemes: the existing 'standard' practice and a proposed 'RCF enhanced' practice with a number of preventative and remedial procedures. In all cases, the results showed a negative benefit (cost) during the first years due to the initial increase in cash outlay. But in most cases, this cost is paid back and the net present benefit of the enhanced method increases over the life of the asset.

The positive net present benefit comes about because most measures to prevent RCF have the long-term effect of reducing loads upon the track components in general, reducing the level of routine maintenance and, in some cases, delaying or eliminating the need for major renewals. In one case, for example, the initial payback occurs in the



**Figure 5:** Net present benefit (NPB) of seven RCF sites subject to anti-RCF maintenance. For each point, the 'y' value is the net cash value to the stakeholder at the time indicated (the 'x' value). The negative values at the start represent the initial investment. The '0' crossing indicates the time to investment payback. Large negative slopes indicate major reinvestments such as renewals.

- Ruscombe Junction
- East Somerset Junction
- Swindon East
- Milton S&C
- Reading West
- East of Cowley Bridge - Up Main
- Acton Down Main

first two years and there is a significant reinvestment at year nine. But the final net present benefit after 20 years is £166,000 for just this one site, indicating that the anti-RCF maintenance scheme could bring about a substantial overall cost reduction.

**IMPROVING STANDARDS**

While some uncertainties remain, we now have a credible explanation for the mechanism that produces RCF, reasonable tools to predict it, and valuable insights into the factors that produce conditions likely to initiate RCF. We also know that RCF can happen even when vehicles and tracks are well within current safety standards. Railway Group Standards ignore many important factors for the optimised operation of the railway system. They focus primarily on railway operating safety rather than operational effectiveness, notwithstanding that the latter can become a safety issue. WRISA's research has shown that key system variables that are within safety limits can contribute to RCF. It follows that we need to establish sustainable operational limits to reduce RCF to

acceptable levels and to restrain key system variables to levels that increase asset life, reduce the need for maintenance and act as best practice limits on component design. These considerations may well apply to other crucial aspects of system performance such as ride quality and component wear. Without question, however, the generation of sustainable operational limits will require the participation of all stakeholders to produce performance-based operating limits that are practical as well as affordable, leading to an optimised railway system.

**Further reference**

- Rail Safety and Standards Board Systems Interface Committees (SIC): [www.rssb.co.uk/sysic.asp](http://www.rssb.co.uk/sysic.asp)
- Vehicle/Track SIC: [www.rssb.co.uk/vt\\_sic.asp](http://www.rssb.co.uk/vt_sic.asp)
- Reports and recommendations: [www.rssb.co.uk/vtrar\\_sic.asp](http://www.rssb.co.uk/vtrar_sic.asp)

**BIOGRAPHIES – Andy Doherty, Steve Clark, Robert Care and Mark Dembosky**

Andy Doherty is Director of the Railway Systems Engineering Group within Network Rail and Chairman of V/T SIC, the inter-stakeholder group responsible for RCF research and development in the UK.

Steve Clark is a Principle Investigator for TTCI, which operates the Transportation Technology Center in Pueblo Co, USA.

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