SQUATS AND STUDS
similarities and differences

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scope

• squats
  – What are they: historical work
• “studs”
  – What are these?
  – Similarities and differences c.f. squats
• conclusions
What do we mean?

• What is a “squat”?  
  – What are they?  
  – What do they look like?  
  – In what ways are they similar to squats?  
  – In what ways do they differ from squats?

• What is a “stud”?  
  – What are they?  
  – What do they look like?  

• Why should it matter?  
  – Concentrate here on observations and metallurgical analysis
background

• **Historical work**
  1. British Rail Research
     • Clayton, Allery, Frederick etc
  2. France
     • Boulanger etc.
  3. Japan
     • Ishida, Kondo, Sato etc.

• **What can we learn from this?**

• **What does it tell us about “squats” and “squat-type defects” / “studs”?**

  **NB** This is not intended to be a comprehensive historical survey: contributions that illustrate significant points.
recent work

1. Stephen Marich and colleagues (Australia)
   - many similar observations to ourselves
   - different conclusions
2. TU Delft
   - Many publications in “Innotrack” project and elsewhere, including at this conference
3. Our own work
   - some results presented here from several railway systems, including heavy haul
   - Initial work presented at CM2009 in Florence
   - Some advances presented here
   - Two more comprehensive papers accepted for publication by Instn of Mech Engrs
   - This is very much “work in progress”
What is a squat?

- Charles Frederick (formerly head of civil engineering research, BRR)

  The term "squat" originated on the western region of BR and it came up as a subject at the Permanent Way Subcommittee. We accepted it as a term which was distinct from head checks or gauge corner fatigue.

  The name derives from the apparent crack formation shape on the running table of the rail; it looks as though a very heavy gnome has sat or "squatted" on the rail producing an indentation shape with two lobes of similar size.

  [personal communication to SLG, 2007]
BRR: appearance of a squat

- excellent cross-section
- two lobes from “squatting” gnome are very clear
- surface-initiated RCF defect

from CO Frederick (BRR)
BRR: initiation of squats

- RCF defects that initiate from cracks at the gauge corner edge of the running band
  - French work on vehicle dynamics has demonstrated that this is the most likely area for squats to develop, and roughly at this angle.

- Periodic squats (at about 3m spacing) probably initiate from indentations made by hard particles picked up on wheels
BRR: development of squats

- “star” of cracks radiating from point of initiation
- Crack develops at roughly 20 degrees to rail surface: *follows sheared grain boundaries*
- Other cracks tend not to develop

Paul Clayton, MBP Allery (BRR), 1982
France: appearance & development of an “English squat”

- the gnome’s bottom is quite clear
- sometimes / frequently there are multiple squats
Initiation of a squat:
UK and French conclusions

• “… the defect is initiated by a crack which starts at the surface of the rail and propagates down the flow lines, that is, in the opposite direction to the plastic shear deformation.” [BRR]
  – see also, “Rolling contact fatigue in rails: a guide to current understanding and practice, Railtrack plc, ref RT/PWG/001, issue 1, February 2001

• “The crack goes down, tilted in the rolling direction at an angle of about 20-25 degrees…. In a ferrite-pearlite steel … the crack follows the pro-eutectoid layers of ferrite inclined by the cold working of the surface” [French]
Japan
growth rate of a squat: Shinkansen

- 40MGT for “seeds” to exist
- 100MGT for surface crack, to edge of elastic/plastic interface

from Sato, Kondo et al, CM1994

Fig. 6. Cause and growth of shelling depending on passed tonnage.
squats:
conclusions from work in 1970s to 1990s

• squats are a **surface-initiated RCF defect**
  – hard material picked up by wheels may initiate periodic squats (3m spacing)

• **apparently associated with driving traction**
  – locomotives and power cars, not curving i.e. not GCC

• **water (possibly liquid lubricant) critical to crack propagation**
  – squats not present in tunnels

• **squats can be well controlled by preventative maintenance of rails**
  – routine, shallow metal removal

• **If not treated at an early stage or removed, squats develop in most cases into a transverse defect (TD).**
studs

• Following slides show
  – squats
  – studs

• Illustrate
  – similarities
  – differences
Superficial appearance of a well developed defect can be very similar.

One photo on RHS is from Hunter Valley coal line (SM2), two from freight line (Aus), one from metro (UK)
location and superficial features

<table>
<thead>
<tr>
<th>squat</th>
<th>stud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not in tunnels</td>
<td>Not in tunnels</td>
</tr>
<tr>
<td>Straights and gentle curves</td>
<td>Straights and curves (not just gentle)</td>
</tr>
<tr>
<td>Locations with high driving traction</td>
<td>Locations with high driving or braking traction e.g. signals</td>
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There are some similarities, in particular the absence of both squats and studs in tunnels.
locations and superficial features (cont.)

- longitudinal profile of opposite rails
  - site from which two of previous “stud” photos came
  - note several coincident defects on opposite rails
  - a “smoking gun”?
“white phase” / white etching layer (WEL)

<table>
<thead>
<tr>
<th>squat</th>
<th>stud</th>
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</thead>
<tbody>
<tr>
<td>WEL exists but is independent of squat</td>
<td>WEL exists in all locations where studs have been found.</td>
</tr>
<tr>
<td></td>
<td>NB No indication from our work to date that stud has formed where WEL has become detached.</td>
</tr>
<tr>
<td></td>
<td>Steve Marich has proposed that this is the mechanism of initiation.</td>
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## Initiation

<table>
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<tr>
<th>squat</th>
<th>stud</th>
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<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Initiates at gauge corner edge of running band</td>
<td>initiates usually in middle of running band</td>
</tr>
<tr>
<td>Initiates from “ratchetting” of surface layer</td>
<td>surface or sub-surface initiation not yet clear</td>
</tr>
<tr>
<td>40-100MGT “typical”</td>
<td>5-10MGT common</td>
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- **SM2 work**

- **Branching of Main Crack**

- **Possible Initiation**

- **Traffic Direction**
<table>
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<th>squat (BRR)</th>
<th>stud</th>
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<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
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**cross section: comments**

<table>
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<th>stud</th>
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</thead>
<tbody>
<tr>
<td>Initial development at 20 to surface</td>
<td>Some cracks at 20, but no consistency</td>
</tr>
<tr>
<td>Crack grows along sheared ferrite</td>
<td>Cracks can exist even if there is minimal (or no) shearing of ferrite</td>
</tr>
<tr>
<td>“ratchetting” is essential for crack growth</td>
<td>“ratchetting” is unnecessary for crack growth.</td>
</tr>
<tr>
<td>Cracks are relatively smooth.</td>
<td>Cracks are jagged and quite broad.</td>
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crack develops in direction of traffic: **hydraulic entrapment and shear mode growth are significant**

There are superficial similarities in crack growth. The result of the crack growing in direction of traffic is that the main indentation, lies at the “running off” end of the crack mouth.
further development

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| **TD *usually* results when squat develops to edge of layer of compressive residual stress** | **no evidence to date that studs develop to cause TDs**
- both freight line and metro experience |

- studs appear **more benign** insofar as they do not break rails, but ultrasonic inspection cannot be made from rail crown
conclusions (1/2)

• The characteristics of squats are well defined from more than 2 decades of work in several countries.
• Squats are a surface-initiated RCF defect.
• “Studs” are a significant rail defect, but they are NOT squats.
• “Studs” have several superficial similarities to squats, in particular their location (outdoors, not in tunnels) and appearance when well developed.
• Significant differences include:
  – crack morphology differs
  – no evidence that studs are a consequence of accumulation of ratchetting strain nor an RCF phenomenon
  – time to initiation: studs<<squats
  – little or no propensity of studs to grow into TDs
conclusions (2/2)

• What are studs if they’re not squats?
• further research is required, in particular
  – to revise minimum actions
  – to identify the root cause of studs, and the mechanism of initiation and development
  – to improve ultrasonic testing and thereby improve safety
  – to develop a solution or solutions that address the root cause of the problem
Acknowledgements and thanks

• **Tubelines**
  – supported this work from the start, even though they had been told by many others that their defects were squats

• **VoestAlpine Schienen**
  – project undertaken by SLG for VAS in 2008 (metro)

• **QR / QR National esp. Nick Wheatley**
  – initiation of SLG to studs on track visit following CM2006
    – track visit May 2011 (freight line)

• **Steve Marich and Steve Mackie**
  – documents, reports, photos from SM2 during a visit by SLG to Australia in August 2009