Technical justification for 6mm T pieces

AUTHOR:

Alex Damas

Transport For London

BACKGROUND

The purpose of an Insulated Rail Joint (IRJ) is to separate two electrical track circuits whilst connecting two sections of running rail. An IRJ consists of two insulated fishplates and an insulated endpost, which is positioned between the two running rails (as seen in figure 1). This assembly is secured by either 4 or 6 bolts dependent on the selected configuration for each installation.

The reliability of IRJs from a signalling aspect has been improved through increasing the thickness of the endpost between rail sections from 6mm to 12mm. On London Underground track, endposts are more commonly referred to as 'T' pieces and are made from polyurethane, a plastic with good resistance to fatigue which is non-conductive.

It is believed that increasing the gap between the rail sections reduces the probability that lipping will occur. Lipping can be defined as either conductive contaminants gathering and bridging the two independent electrical circuits or plastic deformation of the rail head, resulting in metal flow connecting the two sections of rail. When lipping occurs at an IRJ, the electrical circuits are connected and can cause a failure of the signalling system.

Mechanically, the introduction of wider endposts can decrease the life of the IRJ and associated components. There are a number of failure mechanisms introduced through the presence of an IRJ which are discussed later.

MICRO-SLIPPAGE AND OPPOSING RAIL WEAR

Cases have been observed where discontinuities in the rail head, (such as endposts), can result in micro-slippage in the contact patch between the wheel and the rail. This slippage will result in rail burns on the opposing rail, (seen in figure 2), where there is an inconsistency in wheel rail adhesion between each wheel on a wheelset.
In figure 2, it can be seen that the running band beyond the endpost displays a variation in profile. This can be attributed to vertical loading variation, triggered by the "bounce" at the rail gap from wheel unloading. This occurs where there is rapid unloading and loading of the wheelset, transmitting high impulsive loads to the IRJ and associated components. Consequently the disparity in tractive force on the opposing sides of the wheel set creates an imbalance in the frictional forces between the respective surfaces. This in turn unsettles the bogie and can also trigger hunting oscillation, which in severe cases can lead to poor ride quality and excessive lateral forces on track components.

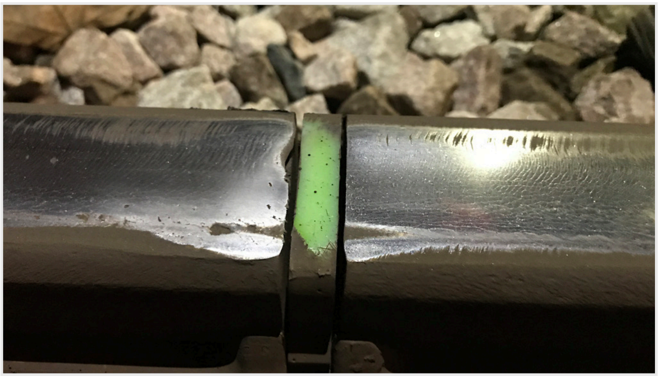
From the Automated Train Monitoring System (ATMS) it has been possible to monitor the vertical acceleration from a train's axle as the wheelset passes 6mm and 12mm endposts comparatively. 5 IRJs of each endpost thickness were identified on ATMS and a review of the recorded accelerations determined that both thicknesses were consistent in magnitude. However, on the opposing rail, the average vertical acceleration significantly increased with an increase in endpost thickness from 11.5 mm/s² to 14 mm/s². This difference can be attributed to the wheelset movement, and from this investigation is seen to be more pronounced at 12mm endposts.

It should be noted that in figure 3 measurements were taken at and beyond each joint. Additionally, on average the recorded vertical accelerations were higher on the opposing rail for 12mm endpost thicknesses, but this did not account for factors such as joint condition, age, radius of the track section etc.

LIPPING

A series of tests were conducted experimentally by The University of Sheffield [1], demonstrating the effect of wider rail gaps on the rate of plastic material flow of the rail head. It was determined that the rate of material flow is consistent for all gap sizes, which supports the application of wider rail gaps to prevent signalling failures. However, further testing demonstrated that plastic flow prevention can more effectively be achieved by installing endposts with higher compressive strength or alternatively hardened rail ends possessing greater toughness.

As seen in figure 4 the properties of the R350 rail steel are more effective at resisting the metal flow generated by tractive force than R260 rail steel. Additionally, the tougher epoxy/glass endpost was more effective at resisting the metal flow than the PA6 (polycaprolactam) equivalent. Neither of these options requires a



Insulated rail joint (IRJ)

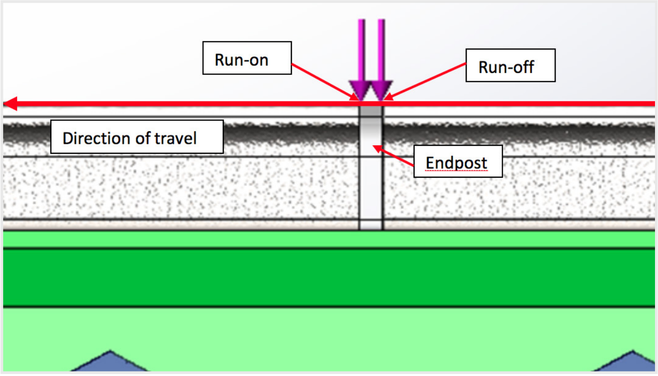


Figure 1: 6mm IRJ model created on Solidworks™

Figure 2: Rail burn beyond a 12mm T-piece

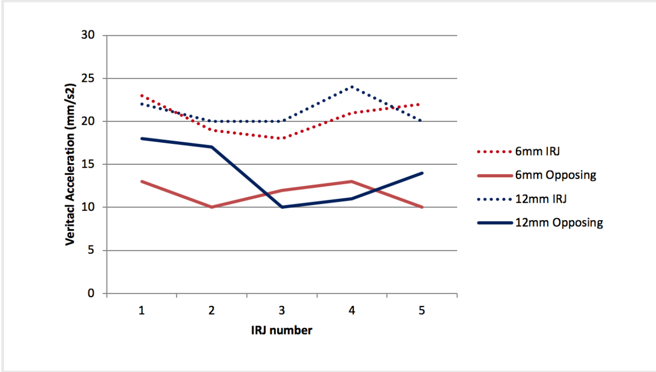
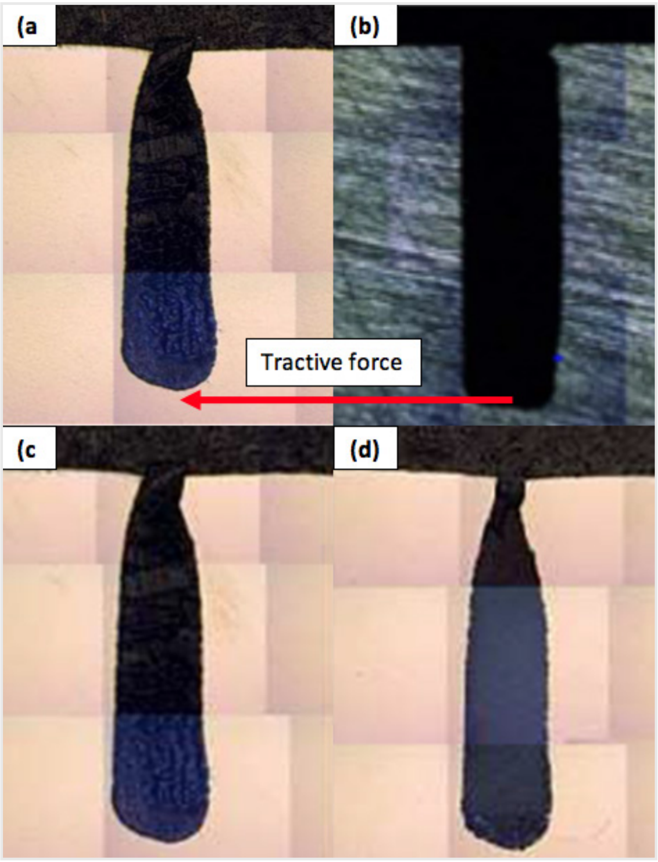


Figure 3: Recorded Vertical Acceleration at 6mm and 12mm T-Pieces



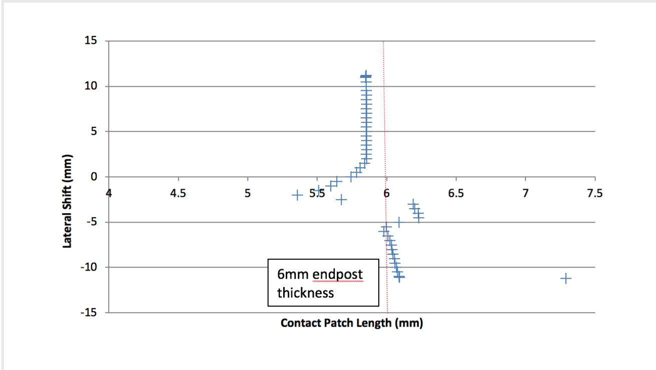


Figure 5 (above): Static contact patch lengths identified within Vampire contact data generation

Figure 4 (left): Disc samples after experiencing 2000 cycles with an applied force of 7.18kN,
4a) R260 rail steel
4b) R350 rail steel
4c) epoxy/glass T-piece
4d) PA6 T-piece [1]

wider rail gap and would therefore reduce the occurrence of the failure mechanisms detailed within this study, whilst still preventing lipping.

CONTACT PATCH BRIDGING

Analysis was carried out using Vampire™ vehicle dynamics simulations software to produce a range of Hertzian contact patch profiles. These were generated at lateral increments of ±0.5mm to each flange limit (representing all shifts on all curvatures) with the following parameters/assumptions:

- 1435mm gauge track
- LT5 new wheel, diameter 790mm
- 56E1 new rail profiles
- Axle load of 75kN
- Hertzian (elliptical) contact profiles
- 0° angle of attack

With the contact patch profiles it is possible to estimate the lengths and widths in contact region within the wheel-rail interface. It should be noted that contact patch data beyond the flange limit was not included within this investigation as these profiles would not reasonably occur in typical operation. This exercise generated 49 unique contact patch profiles which can be seen in figure 5.

Where the contact patch length is greater than a specified rail gap, the wheel and rail are in constant contact. If the contact patch is unable to bridge the rail gap then a loss of contact occurs, resulting in slippage and impact loading at the run-on rail section, consequently transmitting force into the IRJ and the associated fasteners.

As the wheel load is applied to sections of track, the resultant stresses migrate to the surrounding material. Where impact loading occurs, force is applied to a smaller region on the run-on rail section leading to higher concentrations of stress. The result of these effects can induce wheel-rail contact pressure “singularities” above the yield stress of the material and consequently ratcheting, in turn generating wear and cracking within the surrounding material.

Of the 49 cases identified within the study, 35% of the contact patch lengths were greater than 6mm but shorter than 12mm. In these cases the 12mm IRJ assemblies are subjected to a greater amount of fatigue as a result of repeated impact loading.

*It should be noted that a series of assumptions were made within the simulation, which have been detailed. Additionally the percentage of profiles detailed is the “possible contact patch profiles”, not a percentage of the occurrences. Therefore the results should only serve as an indication of the percentage of possible contact profiles which would result in impulsive loading or wheel burn. Finally the amount of shift is heavily dependent on the track geometry (primarily the radius of the site), and so should be consistent at each site (see figure 6).

RAIL DEFLECTION

Track stiffness is the resistance of the track section to deformation to the applied force of

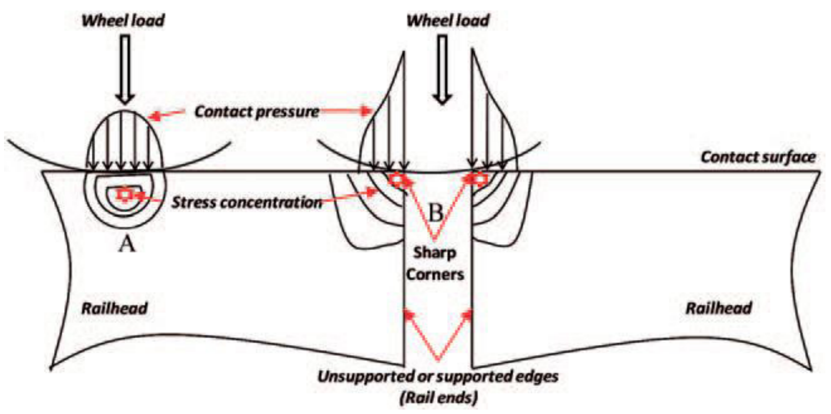


Figure 6: Contact patch pressures [2]

Endpost width (mm)	Average Lost Area (mm²)		MACs		
	Run-off	Run-on	MT	ML	SS
6	90	178	10%	10%	0%
12	578	593	22%	22%	28%

Table 1: Minimum Access Codes from rail profiles

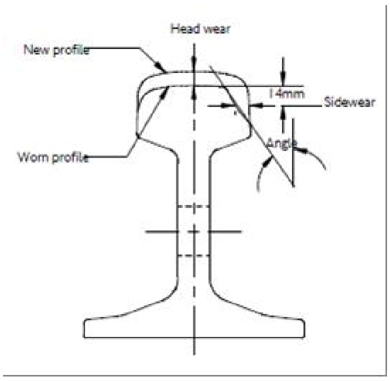


Figure 8: Wear measurements diagram from LU Standard S1159 [5]

the wheels. Sections of rail where IRJs are present are weaker in resistance to bending than plain rail. This is due to IRJs possessing both a lower second moment of inertia and a reduction in elasticity. In laboratory testing [3] 6mm IRJs were found to deflect 61% more than plain rail and were found to be 37% less stiff. This testing was not conducted on 12mm IRJs but it should be assumed that this response will be more substantial where there is a larger discontinuity.

A static FEA simulation exercise was conducted to determine the stress comparison between the 6mm and 12mm endposts. However, the variance in stress profiles and magnitudes were negligible and so have not been included within this report. The negligible differences could be explained when the effects of dynamic loading are considered. Measurements taken in-situ at IRJs [4], have demonstrated that dynamic loading can be up to three times that of the static wheel loads.

When this increase in the applied forces is combined with the weaker bending resistance associated with thicker endposts, joints are more susceptible to rapid degradation. Additionally, as joints degrade due to repeated loading, there can be an increase in failure mechanisms such as bolt looseness, rail height mismatches and rail end batter. Joint degradation therefore is a self-accelerating degradation process, generating progressive increases in joint deflection.

CONDITION OF JOINT

A series of rail profile measurements were taken adjacent to endposts on LU track. The purpose of this investigation was to determine the impact of an increase in endpost thickness on the rail profile. LU standards detail an incremental system for the minimum actions required to be carried out following the detection of significant headwear/sidewear. Any headwear exceeding 14mm is required to be replaced within one week, where this allowable value decreases with an increase in sidewear (see figure 7).

14 IRJs were measured within this investigation and of these 5 were 6mm IRJs and 7 were 12mm IRJs. The exceedances in accordance with LU standards can be seen in table 1. The Minimum Access Codes (MACs) are graded in increasing severity as follows:

- Maintenance Tolerance (MT)
- Maintenance Limit (ML)
- Safety Standard (SS)

Additionally, within Table 1 the Average Lost Area from each profile can be seen, where the average total wear at the rail head is significantly less for both the run-off and run-on for 6mm endposts. These results indicate that the condition of the railhead for 12mm endposts is significantly worse than at 6mm endposts and this is reflected in the vertical accelerations detailed earlier in this report.

These values did not however take into account joint/rail age and it is possible that this could be attributed to a lack of maintenance at 12mm endposts, as opposed to more rapid mechanical wear (see figure 8).

Whilst measuring the endposts sections it was noted that in several cases there was clear voiding between the endpost material, and the rail sections (displayed in figure 9), in particular for 12mm endposts. How this has occurred is not currently understood, but where the endpost material is not in contact with the railhead, there is no physical barrier preventing the occurrence of lipping (see figure 9).

SUMMARY

There are a number of failure mechanisms which are amplified through the inclusion of thicker endposts. These include a higher occurrence of micro-slippage and localised impact loading, more significant deflection and therefore more rapid degradation of the joint condition. The testing conducted by The University of Sheffield [1] demonstrated that wider endposts will delay plastic flow between rail sections; however the delay can also be achieved with optimised material properties for both the endpost material and rail material.

CONCLUSION

From a mechanical perspective there is no benefit to having a thicker endpost. Although the wider rail gap can delay failures due to metal flow or delamination, the failure mechanisms associated with the thicker endpost will ultimately result in a shorter operational life for IRJs than the 6mm alternative. Additionally prevention of lipping can be achieved through altering the materials at the joint without incurring poorer mechanical performance.

Currently where failures occur at IRJs, the thickness of the endposts is not recorded and therefore it is not possible to quantify the number of failures for each endpost thickness. It has also not been possible to identify the number or the ages of 6mm and 12mm endposts on the LU network and so it would not be possible to outline a frequency/failure comparison.

It could be determined that the reduction in required maintenance to reactively remove lipping achieved with the introduction of wider endpost sections is less demanding of maintenance resources. However, the failure mechanisms identified within this report should be considered when determining which endpost thickness is most suitable.

RECOMMENDATION

The extensive costs associated with reactive maintenance to remove defects such as rolling contact fatigue, rail batter and cracks; which can be intensified by wider rail gaps should be considered when determining whether 6mm or 12mm endposts are selected. From a mechanical perspective the 6mm endposts thicknesses are preferable, as the discontinuity between the rails is less substantial and therefore these joints should outperform the thicker alternatives.

It is therefore recommended that where feasible 6mm endpost thicknesses should be installed. A trial should be conducted on the LU network to assess the benefits of optimised rail and endpost materials.

REFERENCES

[1] Experimental modelling of lipping in insulated rail joints and investigation of rail head material improvements – P Beaty – 2016
[2] Development of Optimal Designs of Insulated Rail Joints – Nannan Zong – 2013
[3] The assessment of track deflection and rail joint performance – Maria Gallou - 2018
[4] Revenue service evaluation of advanced design insulated joints – M Akhtar – 2008
[5] Track – Dimensions and Tolerances – London Underground - 2015

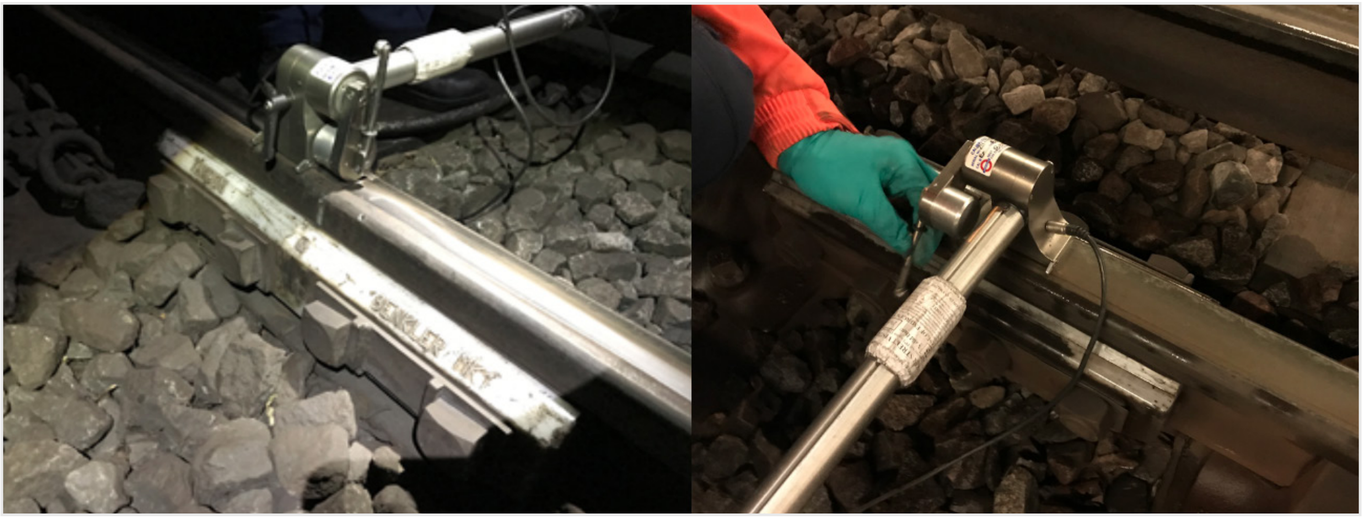


Figure 7: Mini-prof measurement adjacent to endposts

Figure 9: Endpost filler voiding

TECHNICAL ARTICLE

AS PUBLISHED IN

The Journal July 2019 Volume 137 Part 3

Permanent Way Institution

If you would like to reproduce this article, please contact:

Kerrie Illsley
JOURNAL PRODUCTION EDITOR
Permanent Way Institution
kerrie.illsley@thepwi.org