Design and analysis of cast railway crossings: experimentation and simulation

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INTRODUCTION

Progress Rail (formerly Edgar Allen) manufactures switch and crossing (S&C) layouts for domestic and international use and has four UK sites at South Queensferry, Sheffield, Sandiacre and Beeston.
Digital tools such as finite element analysis (FEA) and desktop casting simulations can enhance the design, development and analysis of safety-critical components such as cast railway crossings. To aid the understanding and performance of cast railway crossings, a framework has been developed which in part focuses on the performance of the crossing as a whole and not, as is the case in current literature[1-4], merely just the wheel/rail interface.

The use of empirical data has assisted in the development of an FEA simulation methodology enabling the user to understand the support behaviour beneath the crossing as well as enhancing the knowledge of crossing performance under loading. This, alongside in-track data and historic crossing performance records, consolidates the methodology providing further confidence during design proposals to reduce and eliminate fatigue cracking emanating from the base of the crossing, an example of which can be seen in **image 1**.

This paper outlines the novel crossing framework and; demonstrates a novel finite element analysis (FEA) approach to whole crossing analysis as well as its associated experimental validation.

Image 1: Example of a fatigue crack on a crossing

DESIGN REVIEWS

In the 1970s and '80s Edgar Allen received end-of-life crossing data which enabled the manufacturer to build 'the bigger picture' on crossing design and performance. This would lead to design changes to make improvements but in some instances only succeeded in moving a weakness to a new location, creating lengthy timescales for product development as shown in **image 2**. Whilst this 'trial and error' approach has devolved into a rigorous 'tried and tested' approach, one common theme that remains unchanged in the intervening years is customer feedback. If manufacturers are to develop optimum solutions, they must receive meaningful product feedback; otherwise the industry risks taking a step backwards.

Progress Rail has actively encouraged the recommencement of end-of-life crossing data communication over the last few years. Particular emphasis has been on the crossing lifespan in a bid to analyse the whole spectrum (up to thirty years plus) rather than focus on a localised lifespan range (under ten years). This will enable lessons to be learnt from all crossings – what works and what does not.

AREAS OF INTEREST

Many studies over the years have been conducted on crossings (fabricated and cast) but the majority, particularly in academia, focus on the wheel/rail interaction (WRI) within the wheel transfer area where the wheel transitions from the wing rail to the nose and vice versa. Reducing the impact forces entering the crossings in turn reduces the stresses within them. However, a number of studies focus on 'new' conditions; i.e. new crossing and wheel profiles, neglecting at times the instances where both become worn and as a result the WRI does not behave 'as designed'. At this point an increase is observed in WRI forces on such crossings and stresses are ultimately increased.

Therefore, it is vital to be considering the whole crossing design and not just the WRI. This requires a multi-faceted approach which has led to the development of the crossing framework.

CROSSING FRAMEWORK

The crossing framework, which is still under development, considers the three primary components within the railway system: rolling stock; track (crossings) and support conditions. **See image 3**. The three produce three inter-relationships: wheel/rail interaction; track/support conditions interaction and component degradation.

Through the framework (**image 4**), important influencing factors that impact on crossing design and performance are captured so they can be addressed within an experimentation and simulation methodology in a structured manner. It is important to note that if just one of the primary components, i.e. rolling stock, track, or support conditions, is altered then the crossing service performance will be affected. This paper focuses on one area of the framework for further research, crossing performance analysis, leading to a crossing experimentation and simulation methodology.

CROSSING EXPERIMENTATION AND SIMULATION METHODOLOGY

The experimentation and simulation methodology, consisting broadly of five stages, was developed in consultation with experienced engineers within Progress Rail, customers and major track infrastructure maintainers. A key factor in a crossing's lifespan is the support conditions – their condition will in part dictate the crossing longevity, a function of tonnage and speed. The proposed crossing methodology (figure 5) utilises the unique support system beneath a single-point loaded crossing enabling the experiment to be replicated within the FEA environment.

Stages 1 and 2 are focussed on establishing the support system stiffness profile by applying loads and recording corresponding deflections and plotting a profile curve.

Stage 3 takes a crossing, (applying strain gauges etc.), and places it upon a series of support systems as that tested in Stages 1 and 2. Again various loads are applied with strain and deflection readings noted.

Stage 4 then looks to imitate the Stage 3 testing within the FEA environment. A novel development in this work has been the replication of the support stiffnesses at each crossing support position using rail theories previously applied to plain rail scenarios.

Finally, Stage 5 compares the results obtained during the FEA simulation against those determined experimentally. At this point decisions can be made regarding the crossing design and optimisation.

CASE STUDY: PILOT STUDY AT PROGRESS RAIL SHEFFIELD

A 1:21 acute crossing was placed upon custom supports, (locally sourced materials), with strain gauges positioned underneath. During testing a series of point loads was applied to the crossing ranging from 25-50 tons. The range chosen was based on wheel/rail interaction studies and previous British Rail reports[1-5]. The worst case rolling stock load for dynamic impacts, (the P2 force), on the crossing nose or wing rail are determined to come from the 'first generation electric and diesel-electric locomotive' producing a P2 force of 298kN, (dip angle: 10mRad; Kt: 160MN/m), before any safety factor is applied [6]. Applying 50 tons indicates a safety factor of 1.65 as opposed to the typical 1.20.

Prior to the testing of the crossing, the support system was tested as previously outlined and the stiffness profile obtained. In this particular pilot study for the Stage 3 crossing testing, the peak deflection was recorded alongside the outputs from the strain gauges. This experimental data would then provide the basis for developing the support system stiffness methodologies.

To date there are four methodologies under refinement with a further three under investigation to ascertain their viability based on theory by Fuhrer[7] and Fischer and Gamsjäger[8]. The methods range in parameters needed to generate the deflections and loads for calculating each support stiffness. The unique support stiffness for each support obtained from each methodology was determined and applied to the FEA model.

Based on the four established methodologies investigated, two are capable of predicting crossing peak deflection within 5% of the experimental value. They are capable of predicting the peak stress beneath the point of loading to within 12-16% of the experimental set-up during the 50 ton loading scenario with two being conservative by overestimating

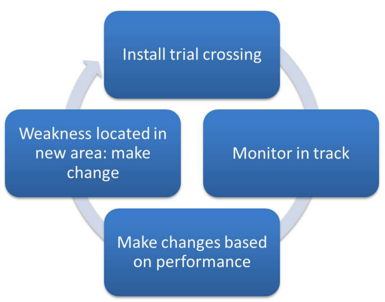

Image 2: Early days 'design' lifecycle

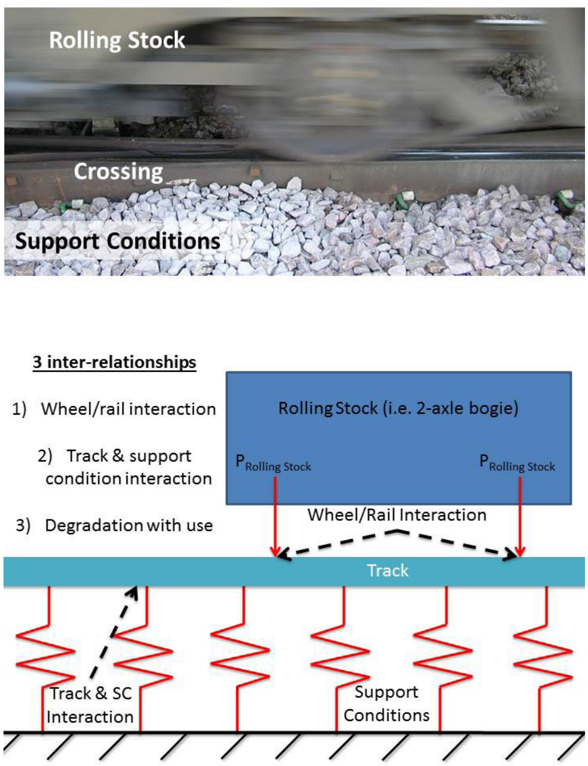

Image 3: Cast crossing framework development

the stress experienced. Again, three of the four methodologies generate the same stress distribution along the crossing length as found during the experiment.

This information can be used to inform crossing design changes. For example, the traditional footprint design (**image 6a**) was altered to improve the structural integrity (**image 6b**) after FEA and casting simulations were carried out[9]. The analysis results demonstrated that for this crossing in its proposed application, modifications were required to remove footprint corner stress concentrations (**image 7a**). These occurred at track support positions beneath the crossing and can become evident during in-service use, especially with poorly maintained support conditions. In this instance the design was changed to have a continuous flange (**image 6b**) to minimise the corners and reduce the stress concentrations (**image 7b**). The continuous flange will increase the resistance to cracking and extend the crossing lifespan, of which the extension is dependent on the local site and support conditions.

Throughout this design, review performance and manufacturing were considered equally to optimise a design for performance but to also understand the implications of such modifications during manufacture.

The introduction of the continuous flange has shown that design-for-service and design-for-manufacture need not be sacrificed for one or the other. Although a balancing act, it is possible to satisfy both criteria.

LESSONS LEARNT

As with any stress analysis study it is mindful to be aware of any pitfalls that may arise and possibly affect the results obtained.

1) Ensure the model reflects the experimental set-up. Utilising video camera during experiments helps capture the nuances of the testing and feeding them back into the model.

2) The fixation of the crossing to the supports can vary. In these tests the crossing was merely placed on top of the supports and not constrained. It was not possible to fix the crossing to the supports due to the workshop environment and handling constraints.

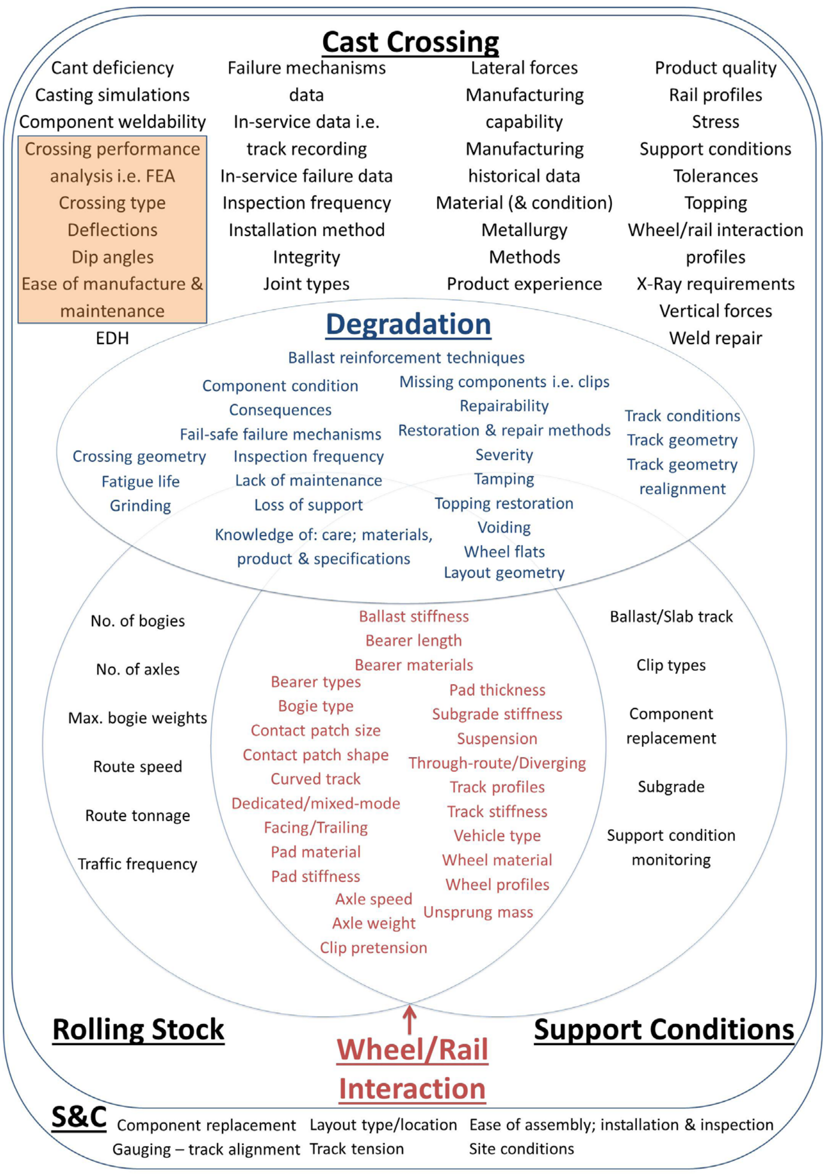

Image 4: Crossing design framework and specific area of interest

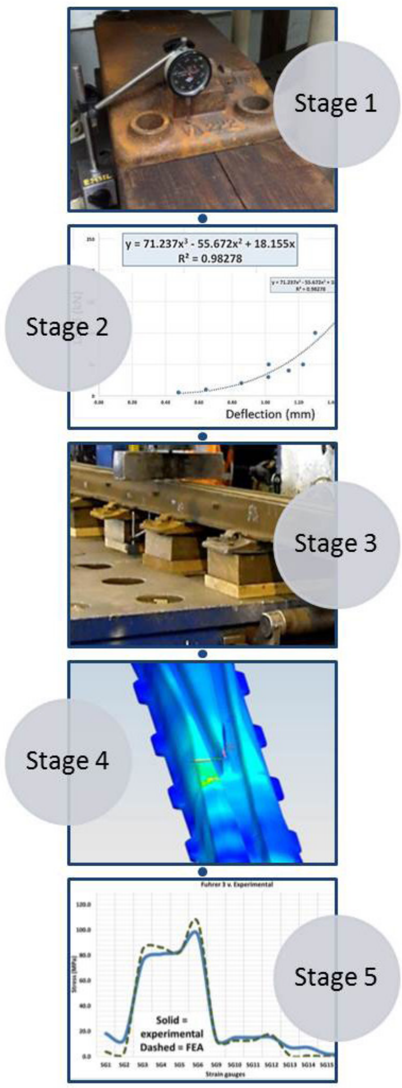

Figure 5: Five stage experimentation and simulation methodology

3) Finally, crossings are of extremely complex design from the outside profile to the internal shapes which vary from manufacturer to manufacturer. This impacts on the crossing bending behaviour when under load. The support stiffness methodologies take this into account, but it should be remembered there are method features which are vital additions to ensure directional solidification, compensation for volumetric contraction, solidification, and thermal expansion and the entry of liquid steel to produce a sound casting. Pattern allowances and machining allowances are built in to make the physical cast crossing.

Keeping these observations in mind will support the effective analysis of a crossing.

CONCLUSIONS

Testing from the pilot study at the Progress Rail Sheffield facility have shown that it is possible to use theory originally intended for plain rail applications in a crossing scenario to determine support system stiffness behaviour beneath a crossing under loading.

The work described in this paper has also demonstrated that a framework in conjunction with digital tools can aid crossing design in an industry traditionally lagging in their application when compared to other high value manufacturing sector companies.

When integrated within a design process, these techniques provide the necessary validation to ensure that design for performance, casting, machining and other processes can be considered in a cost effective manner using computer aided engineering whilst ensuring product functionality is not compromised.

As well as helping pre-empt any potential performance and manufacturing issues their use also ensures actual manufactured components are as close as possible to the customer and designer's original requirements. The proposed framework for cast crossings is still in development, but so far, in its limited use, it has shown the potential to clearly demonstrate benefits and differences between designs whilst ensuring commonality in their set-ups.

Since the pilot study described, an advanced study has been conducted at Progress Rail South Queensferry building on that work. This further work on support system stiffnesses using plain rail-based theories shows promise with additional analysis work being carried out to confirm their suitability in relation to railway crossings.

A more detailed article will be submitted to the PWI in the future covering the formal findings of the recent advanced study at Progress Rail South Queensferry.

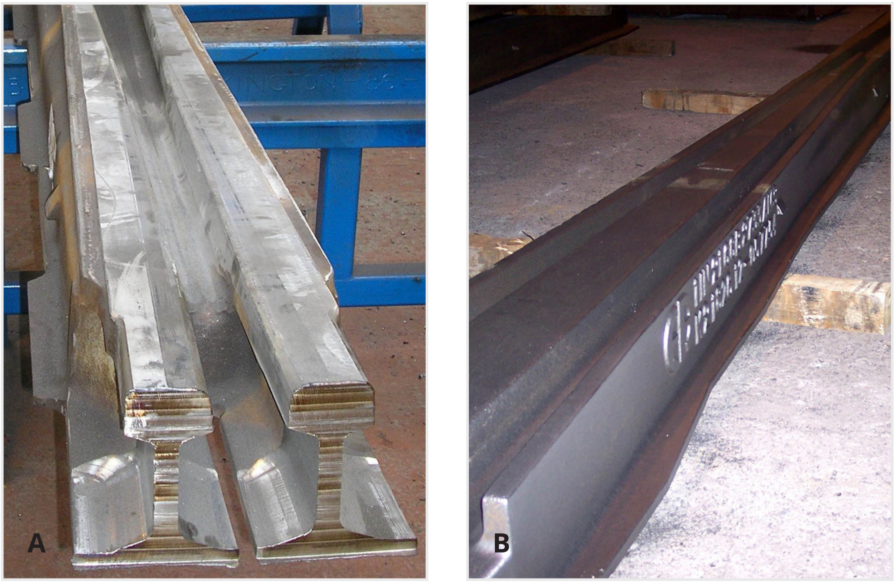

Image 6: Traditional (a) and continuous flange (b) designs

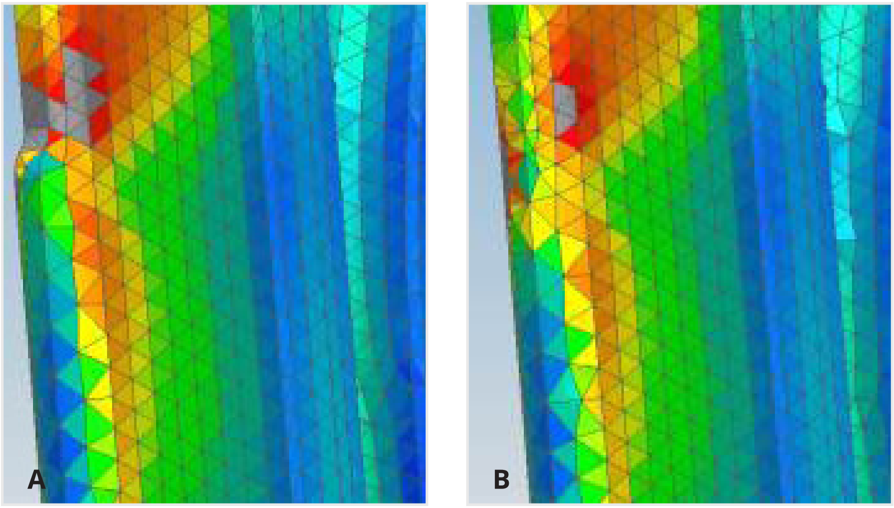

Image 7: Traditional design (a) and continuous flange (b) FEA results

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