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Design and analysis of cast railway crossings: experimentation and simulation (part 2)

H. Persson[1], J.M. Ritchie[2], M.C. Westoby[1] and Y. Chen[2]

[1]Progress Rail Services UK Ltd, South Queensferry, United Kingdom
[2]Heriot-Watt University, Edinburgh, United Kingdom

Abstract

Cast austenitic manganese steel (AMS) crossings are safety-critical components and expensive track components both in terms of unit cost and installation. There can be consequences when crossings fail such as serious accidents, train delays, additional maintenance requirements and costly removal and replacement. This research initially proposed and trialled a 5-stage crossing testing methodology using a pilot study incorporating experimental trials and finite element analysis (FEA) [1]. From this a series of extensive and successful main trials were conducted to test its suitability and reliability. This research further pushed the boundaries on crossing design and analysis by addressing a significant gap within the existing crossing literature. To date whole crossing analysis has never been demonstrated before in this way. In the past, the focus on crossings has always been on wheel/rail interaction using models with no methods features (required to aid manufacture) that focus on the crossing entirely above its neutral axis. This novel crossing testing methodology demonstrates it is possible to analyse a whole crossing in a structured fashion, embed it within a formal design process and provide new insights into crossing behaviour when under load.

This paper will demonstrate the results of the main static loading trials focussing on the repeatability of the methodology and how it can be used to assess design alterations and highlight potential improvements. The impact of manufacturing additions such as methods features and manufacturing allowances, both to aid casting, are also investigated [2].

Keywords: railway crossings, finite element analysis, FEA, experimentation, methoding, simulation.

1 Introduction

Cast austenitic manganese steel (AMS) crossings are safety-critical components and expensive track components both in terms of unit cost and installation. There can be consequences when crossings fail such as serious accidents, train delays, additional maintenance requirements and costly removal and replacement. This research initially proposed and trialled a 5-stage crossing testing methodology using a pilot study incorporating experimental trials and finite element analysis (FEA) [1]. From this a series of extensive and successful main trials were conducted to test its suitability and reliability. This research further pushed the boundaries on crossing design and analysis by addressing a significant gap within the existing crossing literature. This novel crossing testing methodology demonstrates it is possible to analyse a whole crossing in a structured fashion, embed it within a formal design process and provide new insights into crossing behaviour when under load.

To date whole crossing analysis has never been demonstrated before in this way. In the past, the focus on crossings has always been on wheel/rail interaction using models with no methods features (required to aid manufacture) that focus on the crossing entirely above its neutral axis. The early pilot study indicated that it was possible to replicate results from an experimental set-up [1] and the extensive main trials proved its capability. From the latter, a formalised 5-stage crossing design and testing methodology was developed.

Stages 1 and 2 consider the supports beneath the crossing and the associated support stiffnesses and how these should be distributed across the crossing. Stage 3 involves the physical static load testing of the crossing, defining and measuring the key parameters of interest, with Stage 4 replicating and comparing the experimental set-up and results from Stage 3 using FEA. Finally, Stage 5 evaluates the results across the entire methodology, such as the comparison of crossing design alterations and alternative in-situ critical support scenarios, facilitating the understanding of the physical crossing performance and validating the methodology.

The trials and formalised 5-stage crossing testing methodology are novel in their approach and are now used extensively within the company when analysing other design scenarios.

This paper will demonstrate the results of the main static loading trials focussing on the repeatability of the methodology and how it can be used to assess design alterations and highlight potential improvements. The impact of manufacturing additions such as methods features and manufacturing allowances, both to aid casting, are also investigated [2].

2 Methods

Focussing on but not exclusive to acute crossings, the 5-stage crossing testing methodology served as the backbone to the overall crossing design and analysis research in this paper and is divided into 5 key stages.

A number of changes were incorporated into the experimental design and testing following the pilot study (conducted in a works environment) and these can be summarised as follows [2]:

- an increase in the number of supports beneath the crossing leading to the removal of the overhang and cantilever effect that previously impacted on strain gauge results;
- the opportunity to test two crossings (1:21 standard design and a 1:21 modified design based on the standard design but modified internally and around the footprint to assess perceived benefits);
- an increase in the number of deflection points utilised as well as an increase in strain gauges on the bottom of the crossing to enhance the data collection;
- a load cell to accurately record the load transmitted into the crossing with a bespoke rig to enable accurate wheel(ram)/crossing contact; and
- a variety of contact patch positions to mimic the wheel/rail interaction in the wheel transfer area but also wheel flat impacts outside of the wheel transfer area.

Within the FEA stage (Stage 4) two rail-based theories (Fischer & Gamsjaeger and Fuhrer) were adapted for use in analysing railway crossings, enabling the determination of the stiffness variation in the supports along the crossing length. This capability was central to the subsequent effectiveness and validation of the FEA outputs when compared with the experimental results.

Two crossings, one traditional and the other modified, were then subjected to the same support conditions and load magnitudes and positions. Using these defined parameters across both crossing designs enabled informed results to be captured and meaningful comparisons and assessments made regarding proposed design changes. This particularly illustrates how the researched and validated methodology can inform engineers regarding proposed design changes well before any expensive manufacturing prototypes need be made.

Follow-on studies also further investigated crossing performance by comparing experimental results with FEA on the effects of increased stress and deflections due to wheel flats and voiding at various positions across a crossing, providing new insights into how FEA modelling can inform both future crossing design and on-site maintenance. In addition, some early work regarding the effects of multi-axle loads on crossing performance were simulated, providing interesting load distribution results.

3 Results

The outputs from this research [2] have shown that a whole crossing and its supports can be successfully modelled using FEA with the results producing an excellent match to the experimental data. Load points within the wheel transfer area (where the wheel transitions from the nose to the wing rail and vice versa) achieved predicted FEA stresses within 10% of the experimental results, particularly at the crucial narrowest and most vulnerable points in the crossing as shown in Figure 1. Similar accuracies were experienced in mid-bed scenarios outside of the wheel transfer area designed to simulate the impact of wheel flats. Following on from the initial pilot study [1], that reiterated that rail-based theories can be adapted to analyse railway crossings.

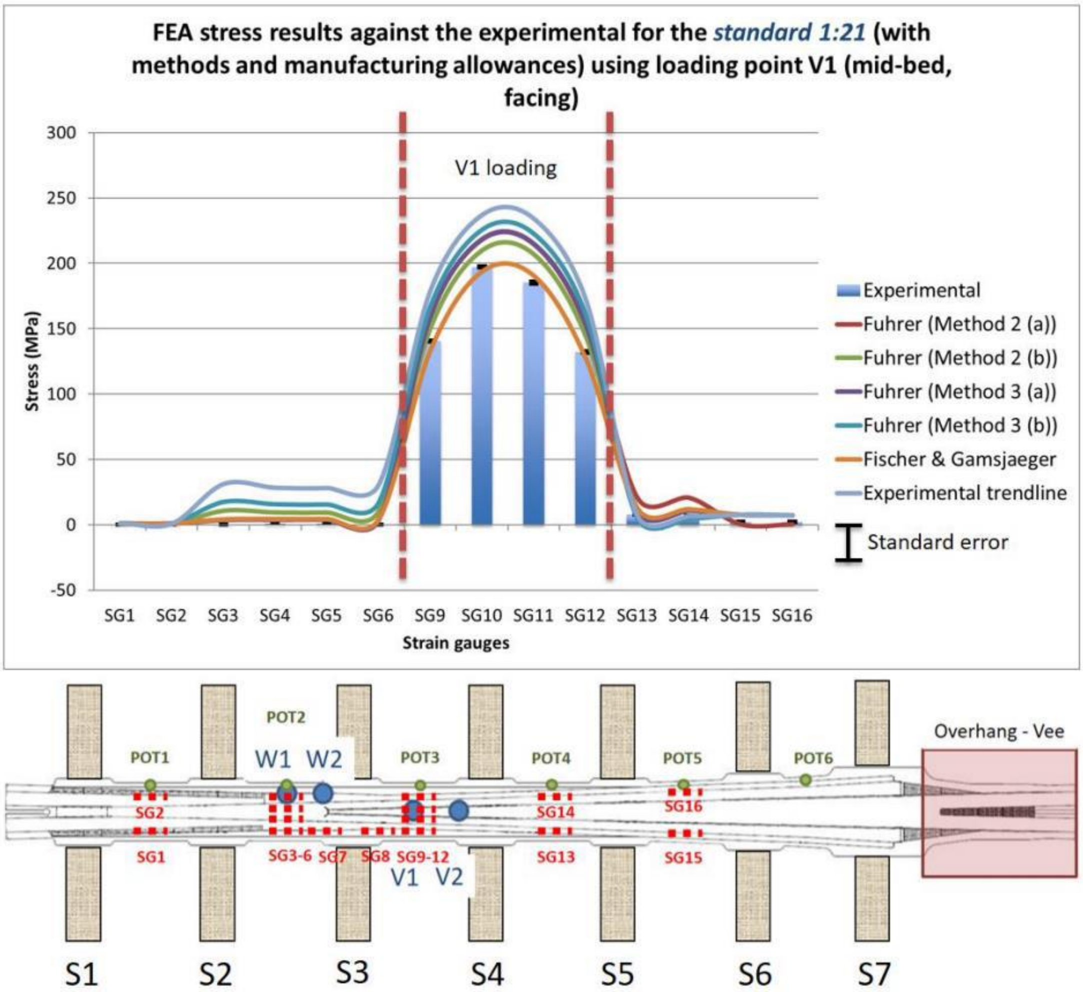

Figure 1: V1 loading point (mid-bed, facing) - evaluation of the FEA stress results against the experimental data at 50 tonnes (standard error range: 0.0-0.8MPa) [2]

This accuracy of the FEA results was validated experimentally for both the standard and modified designs. The modified design applied during both experimental and FEA trials demonstrated stresses lower than the original standard design as demonstrated in Figure 2 [2]. The introduction of the modified design (altered internal design and footprint) has a positive impact on the crossing stresses. The majority of the strain gauge readings reduced in value and, even in the instances where slight increases were noted, did help to promote a safer gradual change in stress along the length of the crossing as opposed to sudden step changes. The design modifications result in lower peak values encouraging more of the crossing to withstand the load, moving stress concentrations away from isolated areas doing all the work.

An additional study comparing the effects of manufacturing allowances and methods features on the FEA model in comparison to the experimental data demonstrated the need to include them during the analysis stage. The increased accuracy in results was not limited to the immediate loaded area, it their effects were experienced in the surrounding beds (the distance between each support). The results illustrated that such features add to the stiffness of the crossing, that their inclusion is vital in producing accurate FEA results and that they therefore must be included during crossing design, analysis and development.

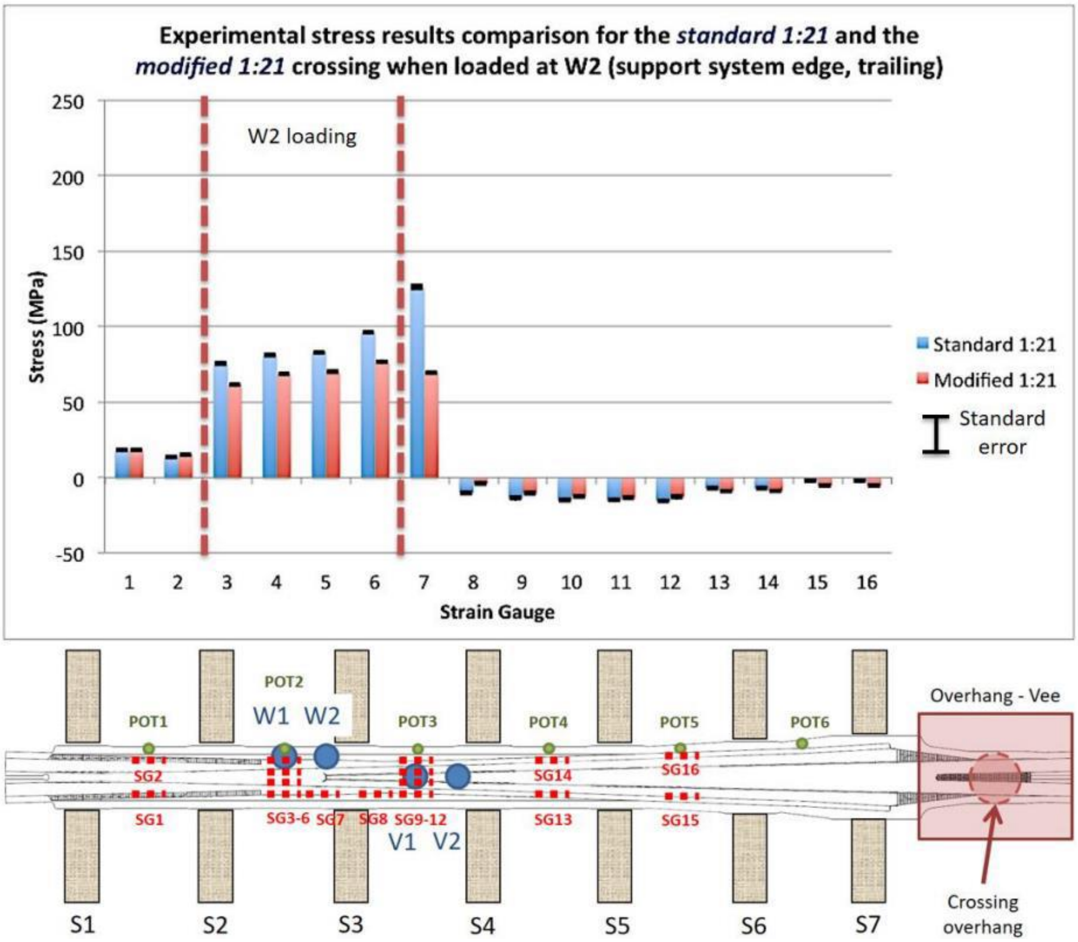

Figure 2: Comparison of the standard & modified designs for the 1:21 crossing at loading point W2 (support system edge, trailing) experiencing 50 tonnes (standard error range: 0.0-0.7MPa) [2]

4 Conclusions and Contributions

The whole crossing analysis approach incorporating experimentation and FEA had considerably changed the manner in which crossing behaviour can be studied. The capability to investigate the effects on new designs - and alterations to existing designs -with confidence now form a significant research foundation on which to extend the modelling and experimentation of these critical rail network components into other domains such as dynamic analysis, materials science and support conditions, to name but a few.

The research also demonstrated that the stiffness varies along the crossing length. A blanket stiffness cannot be applied along the entire crossing length but rail-based theories can be successfully applied to a railway crossing to ascertain each support stiffness values and produce excellent matches in FEA. Likewise the introduction of methods features and manufacturing allowances must be included in the FEA model as they fundamentally change the performance characteristics of a crossing.

The subsequent direct impact of the methodology's application industrially within the partner company can lead to reduced development costs due to the ability to digitally prototype, reduced prototype manufacturing and testing costs and design lead times.

This crossing analysis methodology is now a core element of the company's acute crossing design process. The FEA itself and the lessons learnt from the experimental trials have greatly enhanced the design team's visibility and understanding regarding key stress points, crossing physical behaviour and potential material savings within any acute crossing design. Key customers have also engaged enthusiastically with the process through the effectiveness and visibility of the analysis.

Although currently limited in this study to the one model of crossing, other crossing types e.g. obtuse crossings, curved crossings, etc., are now being investigated using the 5-stage crossing testing methodology particularly when evaluating crossing behaviour in extreme loading situations. The methodology is also being extended to help understand how whole crossing performance impacts on other critical parts of crossing behaviour, e.g. critical welds, clamping and lateral forces and torques. In addition, in-situ trials and wheel/rail interaction studies can now be integrated into the 5-stage methodology as further feedback on crossing performance.

A key desired outcome of this research was the capability to understand whole crossing behaviour via experimentation and replicate these in FEA. This was successfully achieved and enhanced the company's understanding of the physical performance of its key products. The crossing design team now has an even deeper understanding of whole crossing performance.

References

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