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Publication date
2017

Document Version
Accepted author manuscript

Published in
Dynamics of Vehicles on Roads and Tracks

Citation (APA)
Markine, V., Liu, X., Mashal, A. A., & Ma, Y. (2017). Analysis and improvement of railway crossing performance using numerical and experimental approach: application to 1:9 double crossovers. In *Dynamics of Vehicles on Roads and Tracks: Proceedings of the 25th International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD 2017)* (1st ed., Vol. 2, pp. 48-58). Article 330.

Analysis and improvement of railway crossing performance using numerical and experimental approach: application to 1:9 double crossovers

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ABSTRACT: The paper presents an integrated approach for analysis and improvement of performance of railway crossings. The approach consists of a detailed finite element (FE) model of a wheel rolling over a crossing (validated against the measured crossing accelerations) and experimental tools installed on the crossings in situ. The studied crossings are the cast manganese steel 1:9 crossings. This type of crossings suffers from severe plastic deformations and cracks. The presented approach has been applied to improve the performance of these crossings and to assess the effectiveness of the maintenance actions.
The obtained numerical and experimental results have helped to explain the poor performance of the crossings. Moreover, a number of the design improvements have not only been proposed, but also effectiveness of these improvements have been confirmed by the numerical simulations and/or measurement results.
The results are presented and discussed. More details are in the extended version of this paper.

1 INTRODUCTION

The paper presents the results of an integrated (experimental and numerical) approach applied to improve performance of a railway crossing. The studied crossing, which is a part of a double crossover, is cast of manganese steel. The crossing angle is 1:9 (Figure 1a-b). This type of crossings, which are quite common on the Dutch railway network, suffers from severe plastic deformations and cracks leading to the spalling damage (Figure 1c) or even to sudden fracture of the crossing nose.

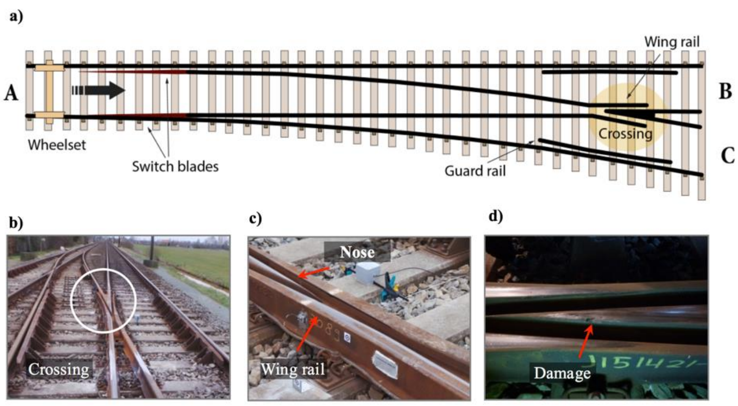


Figure 1. a) Railway turnout; b) Monitored crossover (crossing angle 1:9); c) Crossing instrumentation; d) Spalling damage at crossing nose (Figure from [1]) .

It should be noted that these crossings are mainly passed in the main (facing or trailing) direction and therefore the speed of the passing trains is relatively high (140 km/h). The service life of such crossings in the Netherlands has become prohibitively short and in some cases it is 1 year. Also, the maintenance actions performed on the monitored crossover have not led to improved performance of the crossing. Therefore, TU Delft was asked to analyse the causes of the poor performance of the crossing and to suggest the ways of its improvement. Also, the effectiveness of the maintenance actions performed on these crossings had to be assessed.

In order to answer these questions an integral approach was proposed that consists of the following parts:

- Development of the (explicit) dynamic finite element model (FEM) of the crossing.
- Instrumenting of the crossing and obtaining the dynamic responses (displacements, accelerations due to impact wheel forces) and performing long-term monitoring of the crossings by collecting the dynamic responses and periodically measuring the crossing geometry.
- Improvement of crossing performance by adjusting the crossing design parameters (mechanical and geometrical) using numerical models and implementation of the adjusted parameters in the crossings in situ.

All parts of this approach are presented below. The results of the numerical and experimental studies of the crossing behavior are described in Section 2 and Section 3. The results of improvement of the crossing performance are presented and discussed in Section 4. Finally concluding remarks are drawn.

2 NUMERICAL STUDY

The numerical model used here is the 3-D explicit Finite Element (FE) model of a wheel rolling over a 1:9 crossing as shown in Figure 2a. The FE model has a number of novel features specifically developed to improve the efficiency of the explicit FE analysis of wheel-rail interaction. So that, the finite element mesh in the model is automatically adjusted and adaptively refined (Figure 3) in order to guarantee the sufficient accuracy of the simulation results as well as to keep the computational costs reasonable.

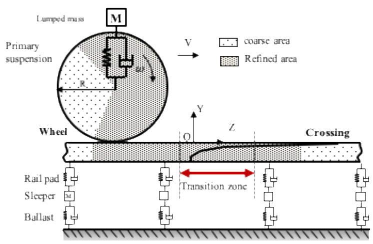


Figure 2. FE model of 1:9 crossing [1]

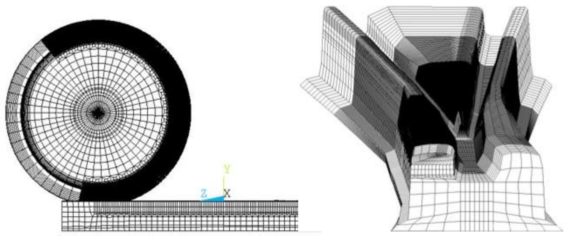


Figure 3. FE mesh of wheel and crossing [1]

The adaptive mesh refinement procedure is based on the coupling of the 3-D model and the complimentary 2-D kinematic model of the wheel and crossing. Using the 2-D model the accurate initial contact position of the wheel on the rail can be determined. Also, the potential contact areas on the wheel and the rail wherein the mesh refinement should be applied are defined. The definition of the refined mesh areas is based on the normal contact clearance. The refined region is defined by the maximum value of the contact clearance (in the numerical examples it was 5mm) that is schematically explained in Figure 4. More information on the adaptive mesh refinement and selection of the contact interface parameters (contact stiffness, element size and integration time step) is given in [1], [6].

Using the implicit-to-explicit sequential solving scheme the dynamic responses of wheel-crossing interaction are obtained. As it was mentioned earlier, to reduce the computational costs of the simulation the initial position of the wheel obtained with the 2-D model was used to facilitate the implicit analysis.

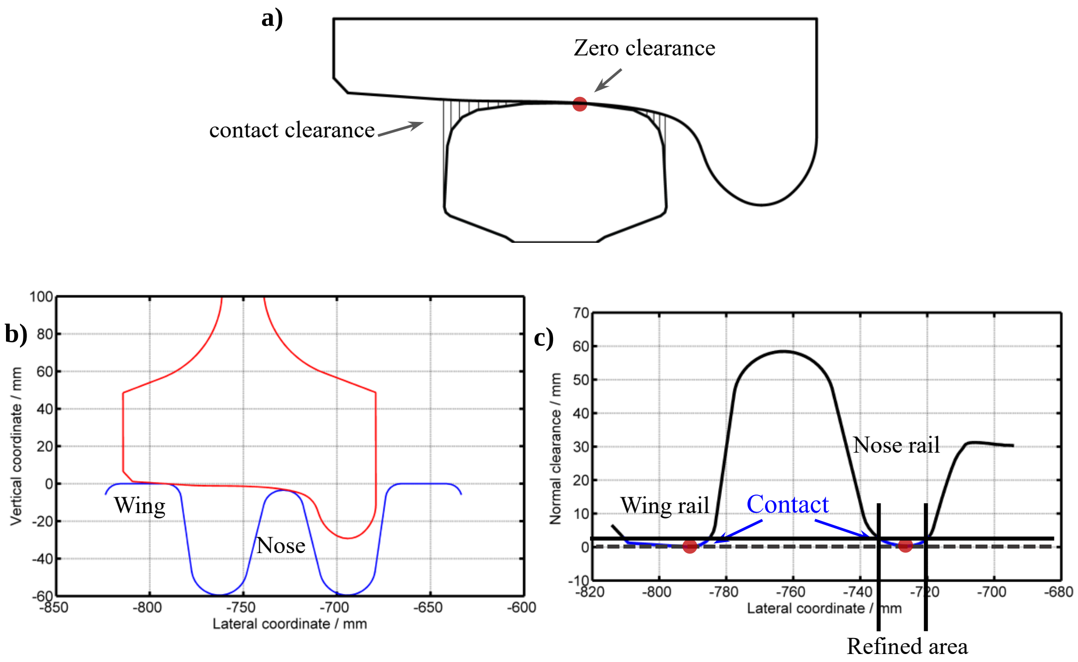
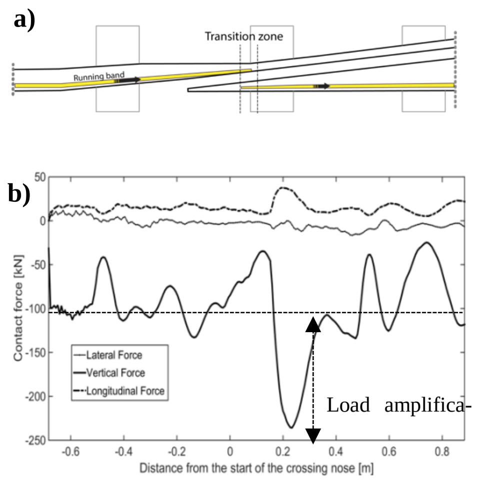


Figure 4. 2-D geometrical model of wheel and crossing (a, b) and definition of refined contact areas (a, c) (from [1]).

Prior to the use in the analysis of the crossing performance, the developed crossing model was validated against the measured accelerations of the crossings due to passing trains [1]. The output of the numerical simulations used for assessment of the crossing performance consists of the contact forces and stresses of the crossing. Example of these results is shown in Figure 5.



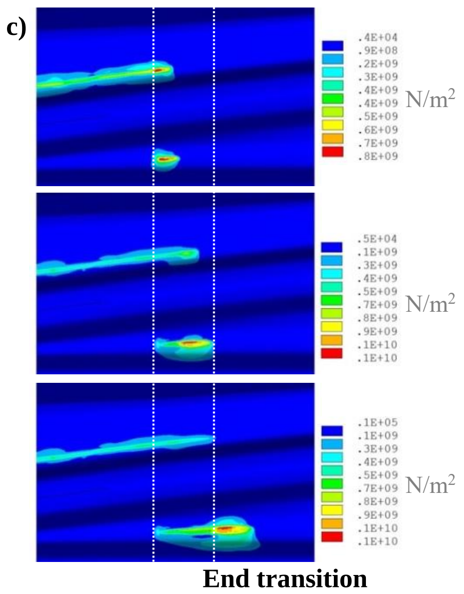


Figure 5. Results of numerical simulation: a) Wheel running band when passing crossing; b) Contact forces; c) Von Mises stress on different stages of wheel passage (from [1]).

As it can be seen from this figure the vertical contact force is drastically amplified with a factor of 2.5 in the transition zone. Also the impact-induced stress exceeds the yield limit of the material (480MPa) greatly, which can easily cause the rapid surface degradations. More numerical results as well as the results of the model validation are presented in the extended version of this paper.

3 EXPERIMENTAL STUDY

In order to validate the numerical model, as well as to gain more insights in the long-term behaviour of the crossings, the 2 crossings were instrumented and monitored for the period of 1 year. The monitoring tools provide the crossing nose accelerations due to passing wheels (for each wheel: the acceleration magnitude and impact location on the crossing) as shown in Figure 1a-b and the rail displacements measured using a DIC (Digital Image Correlation) device called Video Gauge (Figure 6) Such an instrumentation of a crossing has been already implemented on other crossings [2], [3].

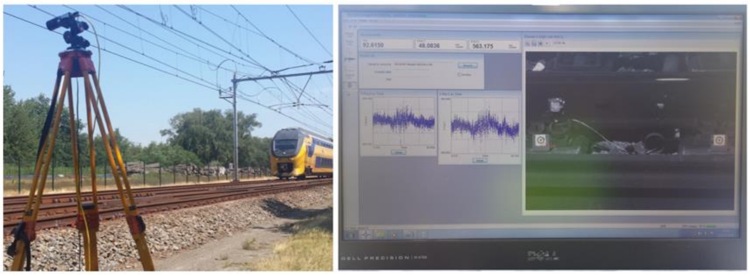


Figure 6. Measuring rail displacements in situ (from [5]): Left: Video Gauge measuring device in the field; Right: Acceleration data collection.

The analysis of the measured responses has shown that the collected data is quite complex and affected by many factors that are usually not taken into account, such as the weather and the day of the week when the measurement takes place. The advantage of continuous monitoring (accelerations) is that the fluctuations in the single day measurements caused by the weather (e.g., temperature, rain, etc.) can be reduced using regression functions.

Figure 7 shows that crossing acceleration responses have a good correlation with temperature variation during the day. Here the temperature variation related to the degree of sunshine, also influences the temperature of the rail.

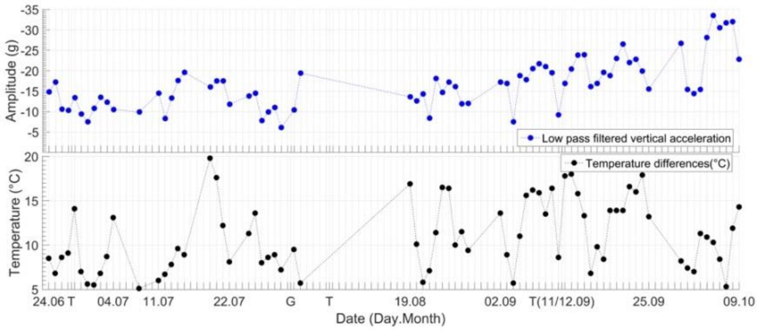


Figure 7. Relationship between acceleration responses and temperature variation: Top: Low pass filtered vertical acceleration during the day; Bottom: Temperature variation. Notation: maintenance moments: “G” grinding, “T” tamping of crossing.

Another example of the long-term measurements is given in Figure 8, wherein the crossing responses (both accelerations and displacements) together with the regression lines are shown.

The measurement results explain the poor behaviour of the 1:9 crossing monitored in situ. Also, the measured accelerations are much higher as compared to that of 1:15 crossings (the blue dot shown in Figure 8). A special attention has been paid to analysis of the effects of the maintenance actions such as tamping and grinding on the crossing performance. From these measurements it can also be seen that the tamping performed on the crossover has no positive effect on the performance of this crossing (the level of the displacements and accelerations has not changed).

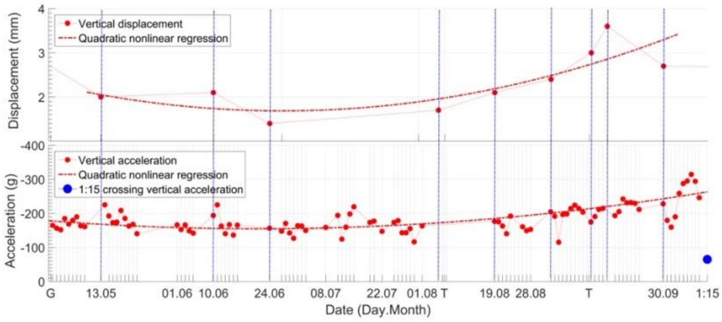


Figure 8. Displacement and acceleration results of a monitored crossing.

4 IMPROVEMENT OF CROSSING PERFORMANCE

The numerical and experimental studies described above have already given some insights on the crossing behaviour in general and the poor performance of the 1:9 crossings. Finally, the numerical and the experiment tools have been used to improve the performance of 1:9 crossings.

4.1 *Geometrical improvement*

Prior to the crossing design adjustment, a parametric study has been performed to identify the crossing parameters that affect the dynamic behaviour of the crossing the most [1]. Based on these results, the geometrical properties of the crossing nose (including the wing rail) have been selected to improve the performance the 1:9 crossing. Similar improvements were achieved earlier for 1:15 crossing in [4], [7].

The results of the geometry modification are shown in Figure 9, from which the significant reduction of the vertical contact force can be seen. The reduction of the contact force will lead to improvement of the crossing performance and to prolongation of its service life. It should be noted, that the geometrical design improvement was obtained in two steps, namely first, using the 2-D model the improvement was proposed, then using the 3-D model the results of the improvements have been confirmed. Details on the geometrical design improvement are given in the extended version of this paper.

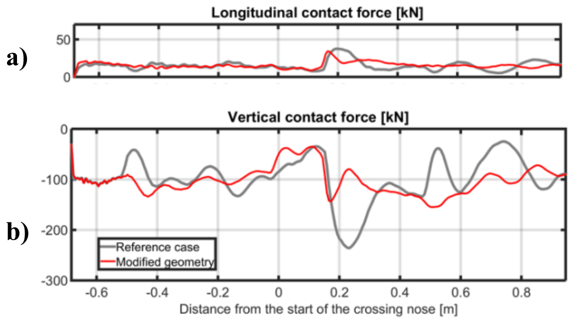


Figure 9. Contact forces of 1:9 crossing with modified geometry (from [1]); a) Longitudinal contact forces; b) Vertical contact forces.

4.2 *Substructure improved design*

As it was earlier proposed in [7], the vertical elastic properties of the crossing support have significant effect on the level of the contact forces and ultimately on the performance and the service life of the crossing. Therefore, during the monitored period on one of the crossings elastic rail pads were installed, while the other was kept in its original design (without elastic pads. The difference in the performance of these two crossings can clearly be seen from Figure 10, which shows the accelerations measured on these two crossings. The accelerations (and therefore, the forces) of the crossing with soft rail pads (blue line) are much lower (around 50g) than the one without soft pads. The difference between the accelerations on these two crossings is continuously growing. These results clearly show the positive effect of the elastic rail pads on the crossing performance.

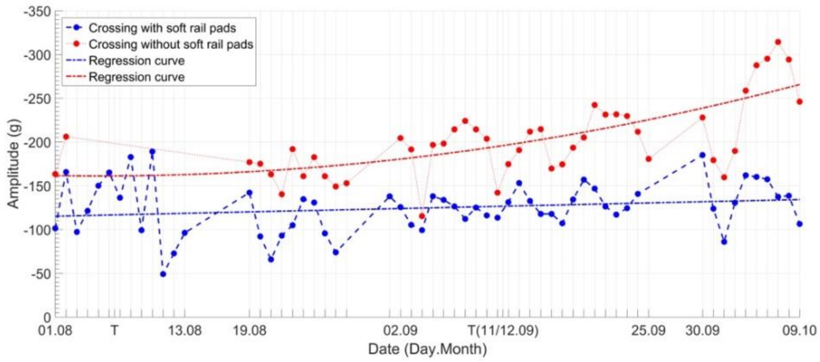


Figure 10. Effect of extra soft rail pads on the behaviour of 1:9 crossings.

5 CONCLUSIONS

The paper presents an integrated approach for analysis and improvement of performance of railway crossings. The approach has been applied to 1:9 crossings that suffered from severe rail damage due to high impact loads caused by the passing trains. The main parts of the methodology are: the 3-D explicit FE model (coupled with 2-D geometrical model to increase the efficiency of the calculations) and the experimental tools to monitor the long term performance of the crossings.

The obtained numerical and experimental results have helped to explain the poor performance of the crossings. Moreover, a number of the design improvements have been proposed. The positive effect of these improvements has been confirmed by the numerical simulations and/or measurement results.

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