Simulation of wheel-rail damage

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Abstract

Wheel-Rail systems are inherently subject to damage caused by the rolling contact and slip stick behaviour between the wheel and the rail. Damage typically manifests itself as wear or crack initiation and growth in the rail. In order to accurately predict this phenomena an accurate understanding of the contact mechanics and crack behaviour is required. In this paper a methodology based on BEM is presented which enables these type of problems to be simulated. Two applications are presented. In the first the wear of an auxiliary rail is predicted and in the second the growth of a crack in the rail due to the rolling contact is predicted.

1 Introduction

Rail systems exploit friction to transmit power, therefore wear and fretting is inevitable. Premature rail replacement , re-profiling of wheels, increased noise, reduced performance and, in the worst case, failure are the consequences of this phenomenon.

In the case of wear a number of authors have studied this problem. A summary of the approaches is provided by [1]. A key factor in accurately predicting the wear is a quantative knowledge of the contact stress distribution and the slip stick behaviour.

The growth of cracks in the rail caused by rolling contact fatigue, fretting or even manufacturing imperfections also requires a quantative understanding of the contact stress distribution. It also requires the use of fracture mechanics techniques in order to predict how the crack will behave.

In the present work a Boundary Element Technique (BEM) is employed to simulate the wear and crack growth in rail wheel systems.

2 Computer Model and Methodology

General

The main types of computer modelling packages for engineering design applications are based on the Finite Element Method (FEM) and the Boundary Element Method (BEM). Although FEM can analyse more types of physical problems than BEM, BEM modelling is generally considered to be easier, faster and more accurate. These advantages are emphasized when modelling in 3D. Because only the surface of the BEM model needs to be discretized, as opposed to the volume in an FEM model, the mesh is generated, checked and modified quickly and easily and far fewer elements are used. Apart from this, BEM has many advantages when it comes to modelling contact problems. A few of these are briefly discussed below:

- FEM packages require the use of special contact elements and highly refined meshes in the contact regions, which increases the overall modelling and solution times significantly.
- BEM has its primary solution variables on the surface of the component being analysed making it extremely well suited to problems involving contact, which is essentially a surface phenomenon.
- BEASY allows the use of discontinuous elements, which is important when modelling problems with singularities. These types of elements allow the solution to become discontinuous, such as is often the case at the edges of contact regions.

As a result of the above, the BEM based computer modelling package BEASY, was chosen for the analysis [2].

3 Application 1 - Wheel Rail Wear

Auxiliary rails are used in railway applications such as maintenance depots and crossings, to lift the wagon or locomotive wheel off the rail. They are located alongside the rail and raise the wheel off the rail by forming a ramp onto which the wheel flange rolls. The operation of the auxiliary rail is shown below in Figure 1.

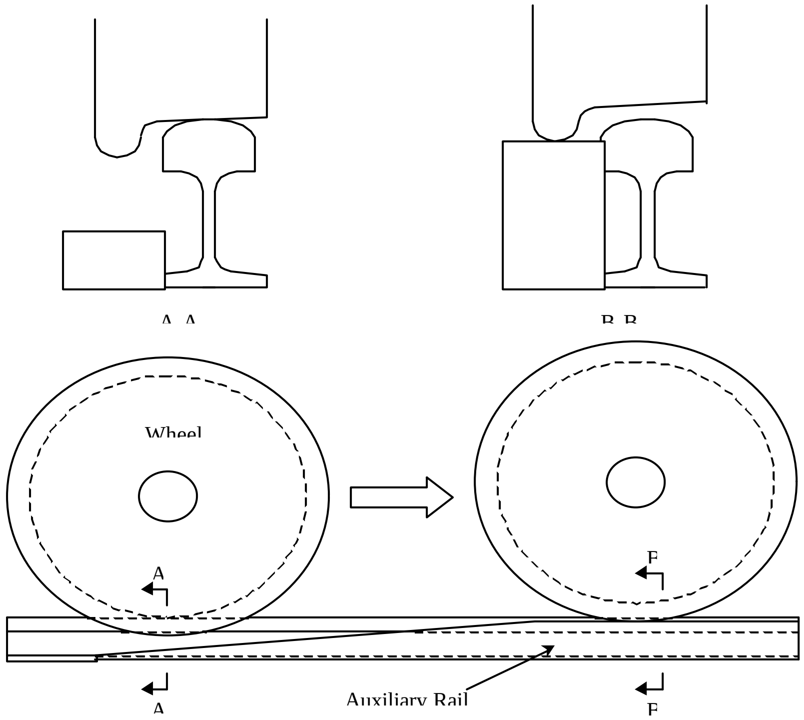


Figure 1. Operation of the auxiliary rail.

The operators of a wagon maintenance depot raised the question of wear of an auxiliary rail that was used in an underfloor lifting system. In order to try to answer this question, information about the contact stresses and contact area between the flange and the auxiliary rail would need to be obtained. It was therefore decided to model the wheel-rail contact problem using computer modelling techniques.

3.1 Modelling Strategy

Symmetry

The BEASY model that was created incorporated a vertical symmetry plane through the middle of the wheel to reduce the number of elements used in the model. Elements do not need to be placed on the symmetry plane in BEASY and this further reduced the size of the model.

Contact

Contact is modelled in BEASY using the software's 'initial gap' boundary condition. This boundary condition defines a gap between two components when the user specifies a positive value, contact with a zero value and an interference fit when a negative value is specified. Initial gap values can be defined over an entire surface containing elements when the contact is conforming, or on an element-by-element/node-by-node basis when the contact is non-conforming.

Loading

An axle load of 31.3kN (half of actual value due to symmetry of the model) was applied to the wheel. The position of the wheel relative to the 50mm wide auxiliary rail was as shown in Figure 2. The rail was fixed on its underside in the BEASY model to simulate the welded connection to the channel section below it.

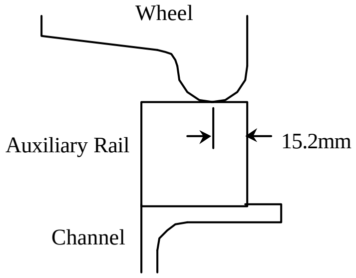


Figure 2. Wheel position relative to the auxiliary rail in Analyses 2 and 3.

Pre- and Post-processing

Several packages were combined to optimise the analysis process. The geometry of the model was generated using the drafting software AutoCAD and then exported to the FEM based package STRAND, which was used as the mesh generator (it has the facility to export PATRAN neutral files which are read by BEASY). Post-processing of the results was done using BEASY.

Pictures of the mesh that was generated are shown below in Figure 3 and Figure 4.

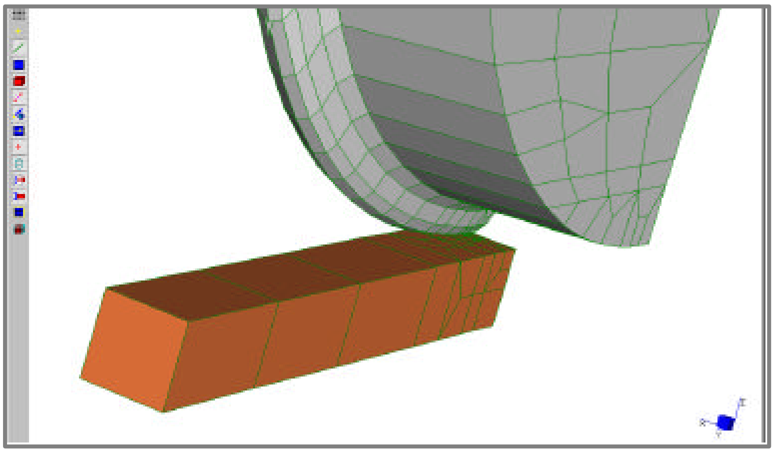


Figure 3. BEASY wheel/rail contact model. Note that the mesh is a surface mesh using two-dimensional triangular and quadrilateral elements.

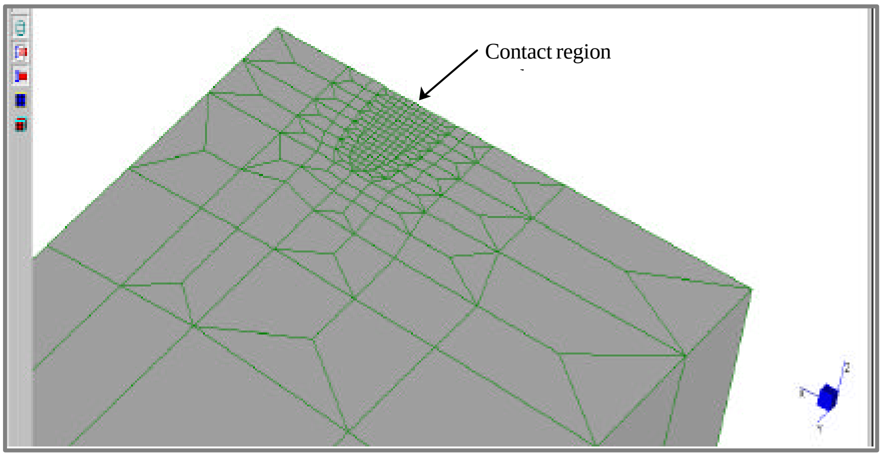


Figure 4. Surface of auxiliary rail showing contact region mesh.

The size of the contact region mesh in Figure 4 was initially guessed with the aid of Hertz's formulas for contact between a sphere and a flat plate.

3.2 Results and Wear Calculation

Stress and Displacement Results
Figure 5 shows a contour plot of Von Mises stresses on the wheel and rail surfaces. Although by default BEASY only displays contour plots where there are elements defined i.e. the exterior surfaces, plots can be made on internal/symmetry surfaces (with no elements) by defining 'display planes' with internal calculation points. The calculation of the solution at these internal points does not significantly affect the solution time.

Figure 6 shows the vertical displacement on the rail surface due to the wheel loading, again using the display plane to show the results in the rail.

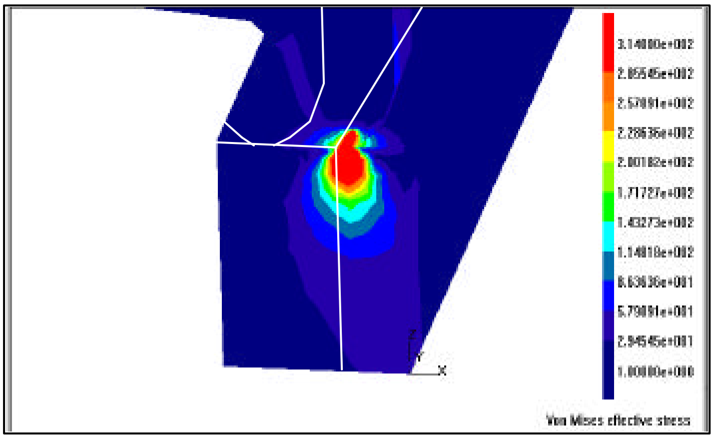


Figure 5. Contour plot of Von Mises stresses on wheel and rail surfaces.

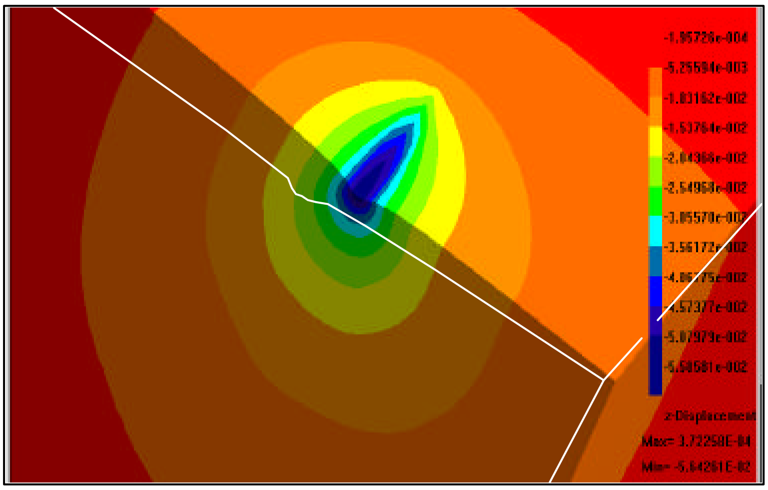


Figure 6. Contour plot of vertical displacement on the rail surface.

3.3 Wear Calculation

Wear was calculated for the analysis using Archard's Law [3]. This is a simple wear equation which states that wear is a function of:-

- Contact load
- Sliding distance (slip)

and is given by the following expression:

$$\text{Wear Rate} = (d.k.W)/\ \sigma_y$$

where d is the sliding distance, k is a load-independent constant that describes the wear rate, W is the contact load and σ_y is the material yield stress.

The amount of slip between nodes as well as the contact loads for the analysis are reported by the software and hence use of the above equation is simple. A single value of the wear rate can then be calculated by averaging the wear results over all the contact nodes. The average wear rate that was calculated was 7.2310^{-6}mm per wheel traversal. For a design life of 10 years, with 24 wheel traversals per day, the total wear for the auxiliary rail is estimated to be 0.63mm.

The results of the analysis indicate the wear on the rail surface is sufficiently low that it will not adversely affect the rails' operation.

4 Application 2 Crack Growth in Rail

In this application the growth of a crack in the rail is investigated. They key elements in the simulation are:-

- the pre-stress in the rail;
- the crack in the rail and the calculation of the stress intensity factor at the crack front;
- the change in the stress intensity factor as the wheel moves along the track.

4.1 Modelling Strategy

As a first step a model was generated to simulate the contact between the wheel and the rail. Figure 7 shows the wheel and the rail cross section included in the model. Figure 8 shows the rail model and the mesh on the contact area.

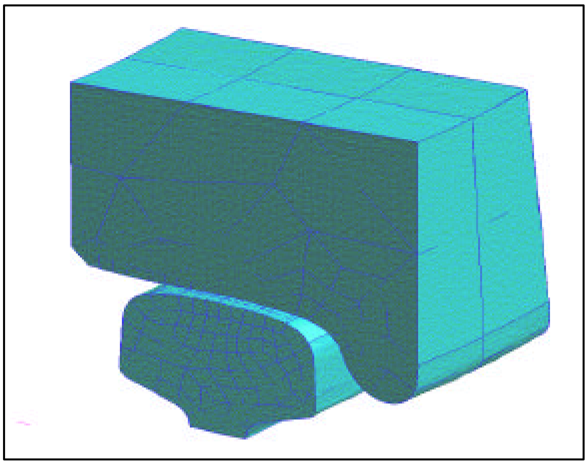


Figure 7. Wheel rail contact model

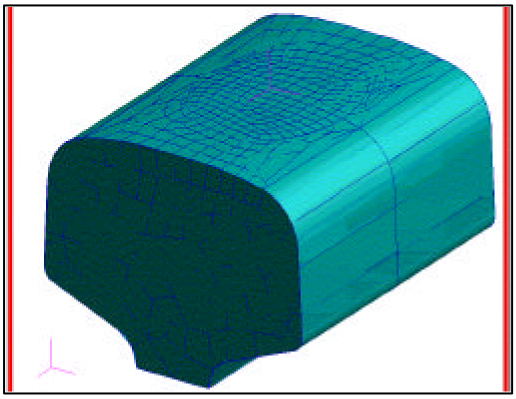


Figure 8. Rail Model showing mesh on contact area

Loading
A vertical wheel load of 135 kN was applied as a pressure load on the wheel inside radius. The wheel was restrained against rigid body motion in other directions.

The bottom of the rail was fixed in the vertical and transverse directions. One end of the rail was fixed in the z direction (along the rail). The other end of the rail was loaded with a traction of 200 N/mm**2 to provide a tension in the rail.

Cracked rail model
Figure 9 shows the location and mesh on the assumed crack. It is clear that positioning of such a crack is very simple and has no effect on the boundary mesh in this case. Thus a study of the effects of different crack size, crack orientation and crack location can easily be performed.

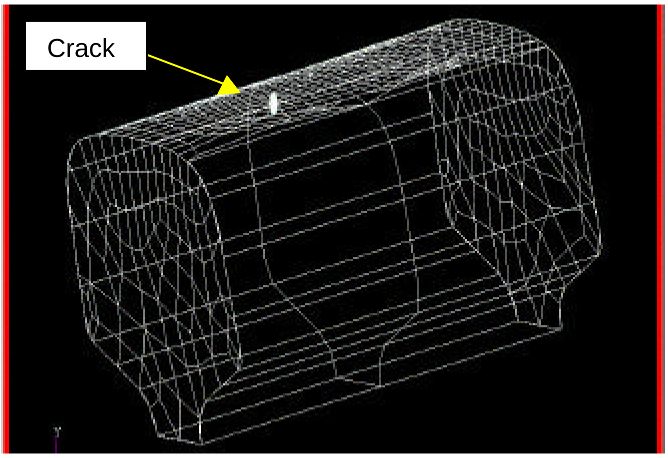
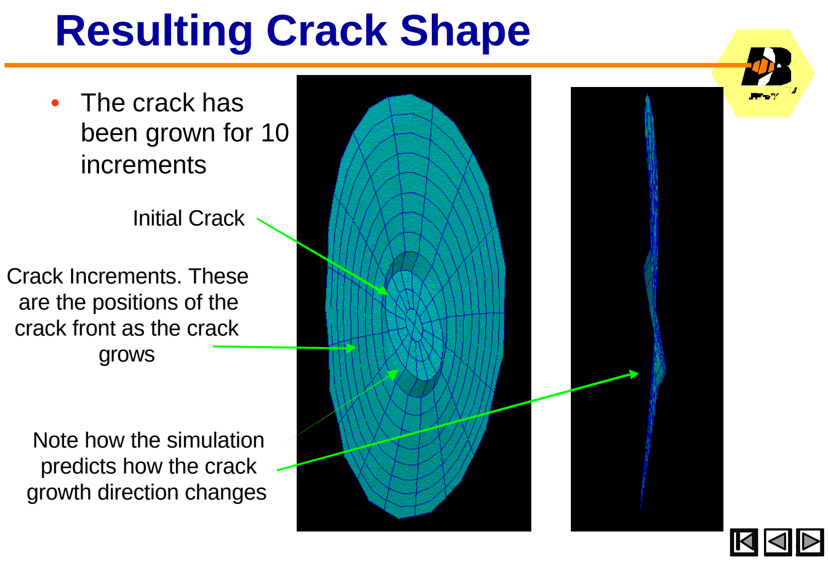


Figure 9. Rail model showing position of crack

Crack Growth
Under the action of the cyclic load obtained from the contact calculation the growth of the crack was predicted. In this application the orientation of the crack was arbitrarily chosen. Figure 10 shows how the crack grows under the applied loading. In the first step the crack grows in a direction of minimum strain energy which is indicated in the crack profile changing into a new plane.

In this case the crack was grown a total of ten increments under the cyclic loading. It is also possible to define loading spectra but this was not done in this case.

The results predict how many cycles it requires for the crack to grow to a critical size and the crack growth rate. The mesh is automatically updated at each step to enable the complete process to be performed without interaction from the user.



Resulting Crack Shape

- The crack has been grown for 10 increments

Initial Crack

Crack Increments. These are the positions of the crack front as the crack grows

Note how the simulation predicts how the crack growth direction changes

Figure 10. Predicted Crack Growth

5 Conclusions

A methodology has been presented to predict the durability of wheel rail systems subject to wear and crack growth.

In the first application the rate of wear has been predicted by the use of an advanced contact analysis coupled with Archards Law.

In the second application the growth of crack like defects in the rail have been predicted by use of an automatic crack growth technology coupled with the cyclic rolling contact load.

The methods and tools presented can be applied to provide critical design information for engineers responsible for railway system durability.

References

[1] Zi-Li Li and Jo ost. J. Kalker "Simulation of severe wheel-rail wear". Proceeding International Conference Computers in Railways VI pp393-402. WITPRESS, Southampton UK, 1998.

[2] BEASY User Guide, Computational Mechanics BEASY Ltd, Ashurst, Southampton, UK, 2000.

[3] Stachowiak G W, Batchelor A W, “Engineering Tribology”, Elsevier, 1993.