Simulation of train–turnout interaction and plastic deformation of rail profiles

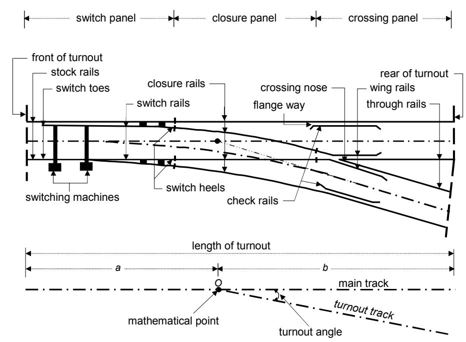
Elias Kassa and Göran Johansson

Department of Applied Mechanics / CHARMEC
Chalmers University of Technology
SE-412 96 Gothenburg, Sweden

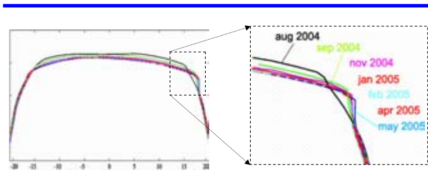
E-mail: elias.kassa@chalmers.se

CHAlmers Railway MEChanics

Components of a turnout



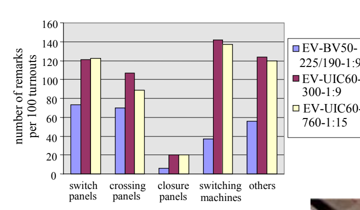
Background



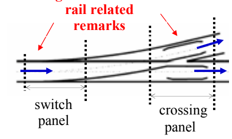
miniprof measurement on a crossing nose in one of SL's turnouts (by A. Santos)

- The profile is measured on several occasions starting from when it was installed
- A significant change in profile due to plastic deformation is observed

Background, cont'd



highest number of rail related remarks



Common damage mechanisms controlling the life of turnout components are
- plastic deformation
- wear
- rolling contact fatigue

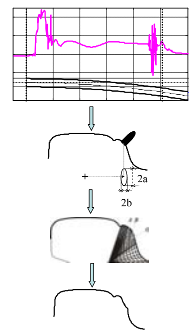
part of a severely worn switch rail

damaged switch rail

Objective

- To demonstrate how train–turnout interaction models can be coupled with finite element simulations to study the development of plastic deformation in certain turnout components
- To study the influence of axle load, train speed and wheel profile on different damage mechanisms (wear and plastic deformation)

Methodology



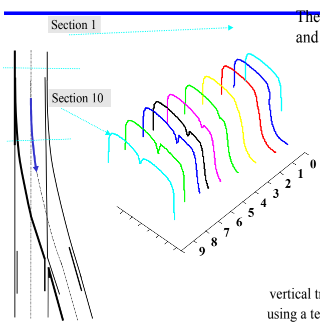
(a) Simulation of train–track interaction, including a parameter study, to predict
- magnitudes of contact forces
- creepages in the wheel–rail contacts
- the dimensions and locations of the contact patches

(b) Determine rail profile with critical loading for wear and plastic deformation

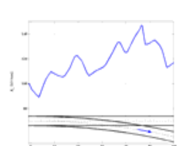
(c) Finite element simulation of large plastic deformation

(d) Geometry change

Turnout features



The rail cross-section varies in the switch and crossing panels leading to a
- variation in contact geometry
- variation in track stiffness and track inertia

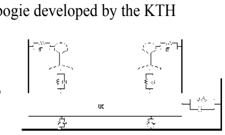


vertical track stiffness along the turnout measured using a test vehicle for continuous measurement of dynamic track stiffness

Train–turnout interaction

The commercial MBS software GENSYS is used to model the dynamic interaction between a railway vehicle and a standard turnout design

- Vehicle model: a freight vehicle model with Y25 bogie developed by the KTH Railway Group
- Track model: a simple track model with a few degrees-of-freedom that is coupled to each wheelset



- Track geometry: turnout type UIC60-760-1:15 (curve radius 760 m, turnout angle 1:15)
- Contact model: Hertz theory for the normal contact, and FASTSIM algorithm to calculate the tangential forces

GENSYS simulation example

In the simulation the following are accounted for

- multiple wheel─rail contacts
- variation in rail cross-sections along the turnout
- variation in vertical track stiffness along the turnout

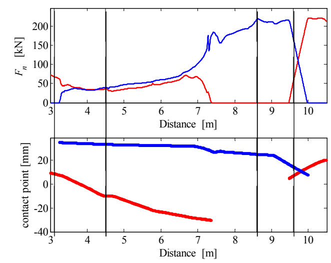
Case study: railway vehicle running through the standard turnout in the facing move

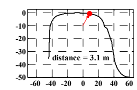
Input data:

- train speed 70 km/h
- axle load 25 tonnes
- wheel─rail friction coefficient 0.3
- S1002 nominal wheel profiles

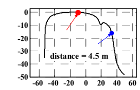
GENSYS simulation example, cont'd

Normal contact forces and contact point locations on the rail

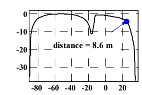




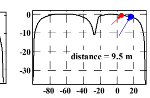
one-point contact



two-point contact



conformal contact



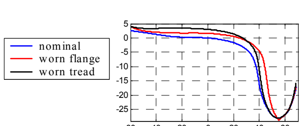
two-point contact on a single rail

Parameter study

For a particular turnout configuration, the contact forces and contact sizes depend on a number of parameters

Parameters for the given Y25 bogie vehicle model

- wheel profile: S1002 nominal, worn flange or worn tread
- axle load: 5, 15 and 25 tonnes
- train speed: 30 – 80 km/h with speed increment 10 km/h

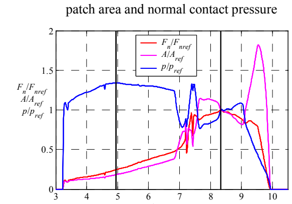


studied wheel profiles

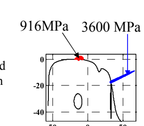
Parameter study, cont'd

train speed 80 km/h, axle load 25 tonnes and S1002 nominal wheel profile

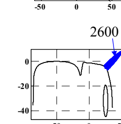
Normalized values of normal contact force, contact patch area and normal contact pressure



cross-section and loading at 4.8 m from front of turnout



cross-section and loading at 8.3 m from front of turnout



The large contact pressure on the switch rail is mainly due to poor contact conditions

Parameter study, cont'd

A parametric study is performed to predict the critical regions for wear and plastic deformation of a switch rail for a given vehicle model

The selection of critical load situations and critical regions is based on maxima in the wear index or the normal contact pressure

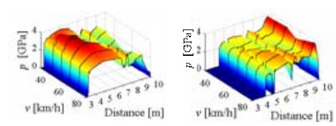
The wear index (W_I) is based on the energy dissipation in the wheel–rail contact

$$W_I = F_x\gamma_x + F_y\gamma_y$$

Identification of the critical regions for wear and plastic deformation is useful in an optimization of switch rail geometry

Results: contact pressure

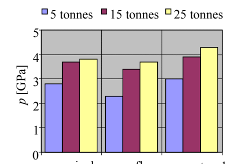
axle load 25 tonnes



nominal wheel profile

worn flange wheel profile

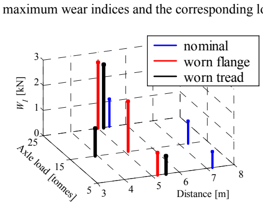
Maximum contact pressure for various wheel profiles and axle loads



- The influence of train speed is small
- For the nominal wheel profile, the contact pressure is maximum at locations 4 - 6 m
- For the worn profiles, several local maxima appear at several locations where there are jumps in the contact point

Results: wear index, cont'd

The maximum wear indices and the corresponding locations

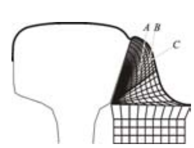


- The location of the maximum wear index is 5 m from the front of the turnout
- The highest wear indices are obtained for lower train speeds (30 – 40 km/h)
- The wear index increases with axle load

Modelling of geometry changes

- The change of geometry of a selected switch rail profile due to large plastic deformations is simulated by means of finite element analysis
- The selection of rail cross-sections is based on calculated maxima in the normal contact pressure from the vehicle dynamics simulation

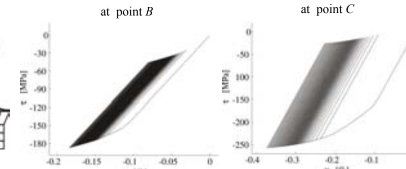
Finite element model of the studied cross-section



The maximum shear stress τ versus the corresponding strain component γ

at point *B*

at point *C*

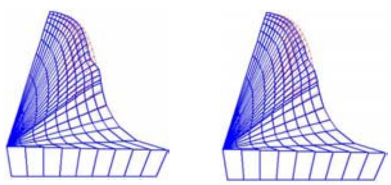


High stresses are located near the loading at the contact surface (point *C*)

Modelling of geometry changes, cont'd

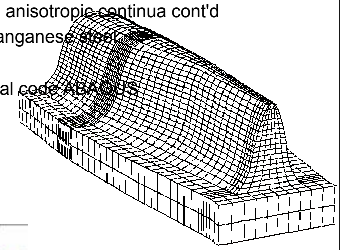
Characteristic geometry changes due to plastic flow after 100 load cycles for two contact patch lengths

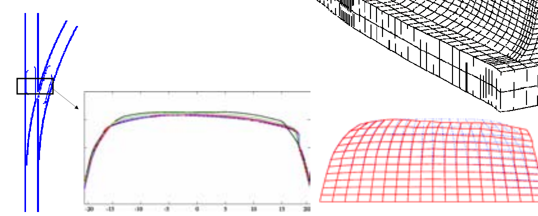
10 mm contact length   15 mm contact length



outlook

- study of discontinuities in an anisotropic continua cont'd
- model calibration against manganese steel
- numerical simulations
- implementation in commercial code ABAQUS





Concluding remarks

- ❖ Simulation of train–turnout interaction, integrated with a finite element simulation to study plastic deformation of a switch rail, has been demonstrated
- ❖ The large contact pressure on the switch rail is mainly due to poor contact conditions
- ❖ Some of the Hertzian contact theory assumptions are rough assumption in the case where plastic deformation and conformal contact are common in turnout simulation
- ❖ The contact pressure is increased by an increase in axle load
- ❖ A combination of high axle load and low train speed results in an increased wear index
- ❖ The influence of wheel profile on contact pressure and wear index is significant

Concluding remarks, cont'd

- ❖ The finite element simulations, performed for different sizes of the contact patch, resulted in cyclic ratchetting material responses near the contact patch
- ❖ High stresses are located near the loading at the contact surface
- ❖ In future work, the influence of other parameters, such as wheel–rail friction coefficient, vehicle type and track gauge, will be studied