Optimisation of Railway Crossings

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Outline

- Research problem
- Research methods
- Challenges and solutions
- Conclusion
Some facts in Netherlands

- 6% of the train delays due to turnouts in 2010, are responsible for 55% of the total disruption time.
- Impact of broken crossings is 28% of the mentioned 55% of the disruption time.

Damage at crossings

Lipping - plastic deformation with cracks on the crossing nose

Spalling  Damaged crossing nose  Head checks
How to solve the problem?
Two approaches
Approach I

Tune the crossing geometry
Effect of grinding

- Impact along the crossing (collected data during 2 hours of train passages)
- Accelerations of nose rail (example of a single train passing at speed of 138.5 km/h)
Adjust crossing geometry

Changing rail profiles

Crossing

Crossing nose

Wing rails
Approach II

Tune the track elasticity
Adjust track elasticity

Rail pads

Under Sleeper Pads (USP)

Elastic baseplates
How ????
Traditional way in railway design optimisation

Predefine $n$ design cases

Evaluate $n$ cases

Best case $\rightarrow$ optimum

Case 1
Case 2
$\vdots$
Case $n$
How to choose the n cases ????
Numerical optimisation problem

Initial design

Minimise

Subject to

Update design using optimisation method

Analyse design

Does the design satisfy convergence criteria?

Done

\[ F_0(x), \quad x \in \mathbb{R}^N \]

\[ A_i \leq x_i \leq B_i, \quad i = 1, \ldots, N \]

\[ F_j(x) \leq 1, \quad j = 1, \ldots, M \]
Evaluation of crossing design based on Dynamic vehicle-turnout interaction
Crossing geometry optimisation
Optimisation problem

Optimise crossing geometry to reduce damages at wheel-rail interface!

\[ F_0(X) \equiv w_1 \frac{\bar{S}(X)}{\bar{S}^*(X)} + w_2 \frac{\bar{W}(X)}{\bar{W}^*(X)} \rightarrow \min \]

- Wheel-rail normal contact pressure \( S \)  ⟷ RCF damage
- Energy dissipation in the contact patch \( W \)  ⟷ Wear
Constraints

- No risk of derailment
- Sufficient support surface when impact occurs
- Constraints of nose rail geometry
  - Smooth-convex cross-sectional shape
  - Monotonically increased height profile
Track elasticity optimisation
Optimisation problem

Reduction of dynamic forces on turnout crossing

- High frequency force on rail ($P_1$)
  - Accounts for damage at the wheel/rail interface

- Low-frequency forces on ballast ($F_{bl}$) and sleepers ($F_{sl}$)
  - Accounts for damage of the sleeper and ballast bed.

\[
F_0(X) \equiv W_{P_1} \frac{P_1}{P_1^*} + W_{F_{bl}} \frac{F_{bl}}{F_{bl}^*} + W_{F_{sl}} \frac{F_{sl}}{F_{sl}^*} \rightarrow \min
\]
Constraints

- Maximum displacement of rail
- Maximum displacement of sleepers
- Maximum deflection of rail pads
Challenges
Parameterisation of crossing design
Parameterisation of crossing geometry
Step I: Choose control cross-sections

(a)

(b)

(c)
Step I: Choose control cross-sections

- Fixed cross-sections I, II, IV
- Tuning cross-sections III, V
Step II: Determine design parameters

- Longitudinal height profile of nose rail

![Diagram showing the longitudinal height profile of a nose rail. The diagram includes various points, distances, and labels such as TP, h1, h2, e, 2e, and 3e, and a graph with axes labeled Height [mm] and Distance from TP [mm].]
Step II: Determine design parameters

- Transvers profile of nose rail (B-spline)
Parameterisation of track elasticity
Parameterisation of track elasticity

- Design parameters: elastic properties of rail pads & USP
Parameterisation of track elasticity

- Design parameters: elastic properties of rail pads & USP
2. Uncertainties in crossing design
Robust Optimisation

optimal: non-robust

suboptimal: robust
3. Balance between model accuracy and computational cost
- MBS simulation
- FEM simulation
- Experimental investigation
Optimum solution
Optimum crossing geometry

- Longitudinal height profile of nose rail

- Nose rail shape
Robust dynamic behaviour

- Shift of impact location
- Reduction of contact pressure

A1-C2 represent different vehicle-track conditions
Optimum track elasticity

- Softer rail pads combined with the USPs
- Rail pads with different properties

*Relatively less soft rail pads before and after the crossing nose than under the crossing nose*
Reduction of dynamic forces
-- Compared to original design

Optimum designs

- Rail
- Ballast
- Sleeper
- combined reduction
How to implement?
Grinding/welding maintenance

Crossing before grinding

Crossing after grinding
Manufacturing process

source from Network Rai Engineering education video: https://www.youtube.com/watch?v=qsCojjLhS68
Concluding remarks

- A methodology of improving the dynamic crossing performance by tuning crossing designs is proposed, including:
  - Adjusting crossing geometry
  - Adjusting track elasticity

- The methodology combines modern optimisation techniques and dynamic train-turnout interaction, and accounts for
  - Multiple assessment criteria in design optimisation
  - Uncertainties in design
  - Realistic parameterisation of crossing designs
  - Balance between accuracy and computational cost
Details of the research can be found in


http://repository.tudelft.nl/islandora/object/uuid:8dac8f02-fe9e-4baa-9503-e9b3d79dd1aa?collection=research