TAMPERE UNIVERSITY OF TECHNOLOGY

Railway Track Superstructure Research at Tampere University of Technology, Finland

Hay Seminar UIUC

28 September 2018

Tiia Loponen

Riku Varis

Riku Varis

Education	PhD student, Railway Structures, Department of Civil Engineering, Tampere University of Technology (TUT) (2013 ->) MSc, Department of Mechanical Engineering, Mechanical design, Tampere University of Technology (TUT) (2012)
Employments	Tampere University of Technology, Research Scientist, Doctoral Student, Department of Civil Engineering, 9/2011 -> Finnish Transport Agency, Superstructure Specialist, 9/2014 – 12/2016

Tiia Loponen

Education	PhD student, Railway Structures, Department of Civil Engineering, Tampere University of Technology (TUT) (2013 ->) MSc, Department of Mechanical Engineering, Applied Mechanics, Tampere University of Technology (TUT) (2012)
Employments	Tampere University of Technology, Research Scientist, Doctoral Student, Department of Civil Engineering, 1/2012 -> Andritz Hydro Oy, structural analyst, 5/2011 – 12/2011 Bronto Skylift Oy, structural analyst, summer 2010

Outline

- Introduction of Tampere and Tampere University of Technology (TUT)
- Track structures research at TUT
- Main topics of the VTI research
- Main topics of the turnout research
- Summary

Tampere, the third largest city in Finland

Tampere

Third largest city in Finland, 230,000 inhabitants

One of the fastest growing urban centres in Finland

The most popular city to live and study in Finland

Tampere3

Tampere University of Technology, University of Tampere and Tampere University of Applied Sciences

- **35,000 students**
- **5,000 employees**

Tampere University of Technology

Established in 1965

Approx. 1,600 employees and 7,900 students (2016)

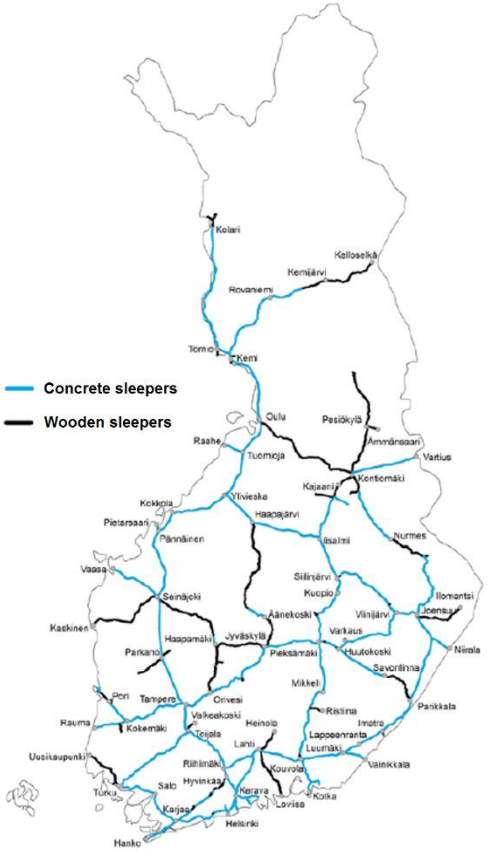
Started operating in the form of a foundation in 2010

Quality assurance system audited by The Finnish Higher Education Evaluation Council in 2014

Collaborates with approx. 230 universities around the world

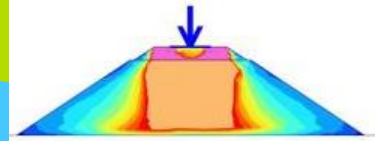
Finnish Rail network

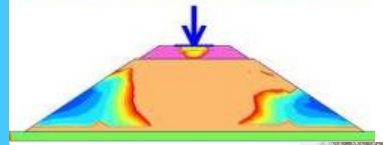
- Length of the whole network is 5926 km, from which 3270 km are electrified
- Most of network (5280 km) is single track
- Owned by the Finnish Transport Agency (FTA)
- Track gauge: 1524 mm
  - Finnish wheelset gauge 1524 mm
  - Russian wheelset gauge 1520 mm
- Rail profiles: 54E1, 60E1, 60E2



Collaboration between TUT and Finnish Transport Agency (FTA)

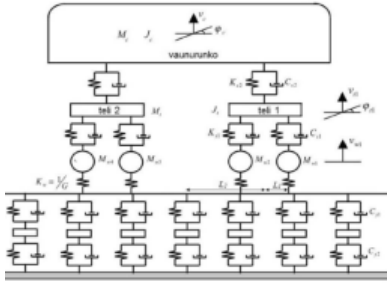
- Cooperation began in late 1990's with RHK by individual research project's
- Several research projects in 2000's
- 2008-2012 Research program **TERA**
- 2013-2016 Research program **TERA 2**
- 2017-2020 Research program **ETEVÄ**
  - Major research volume with FTA
  - Small-scale collaboration with industry, EU, Universities, etc.



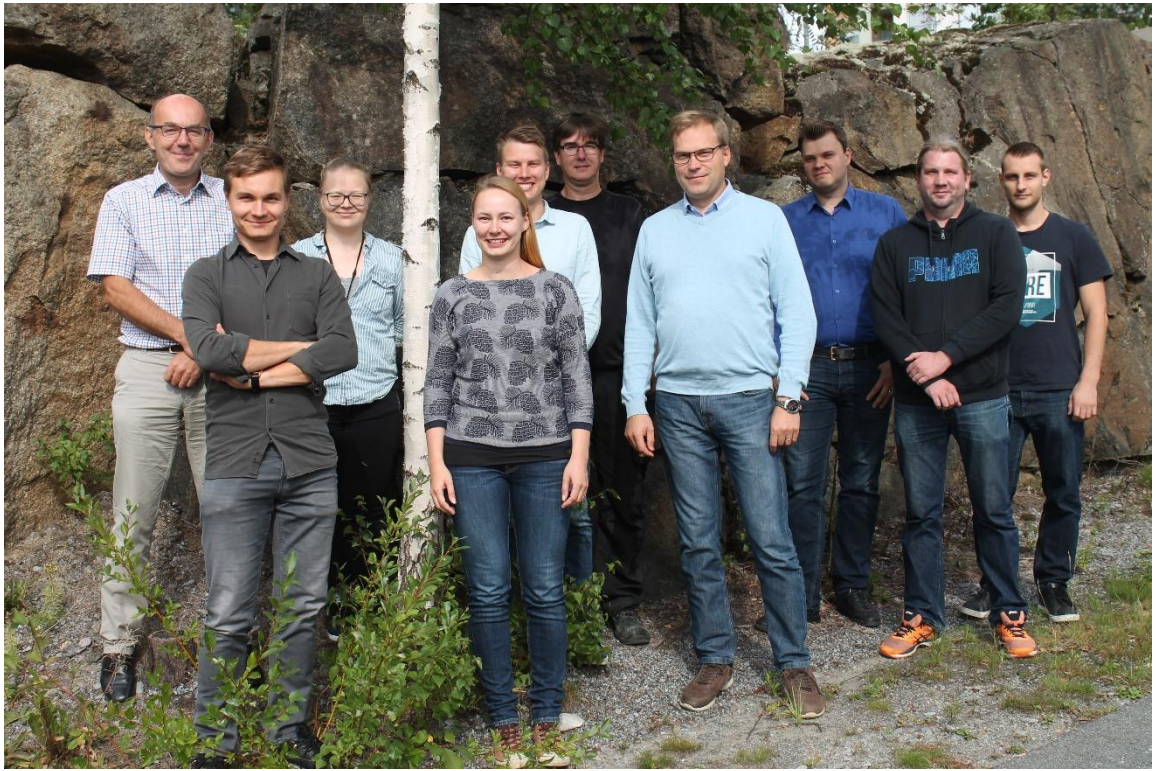


TUT Railway Engineering

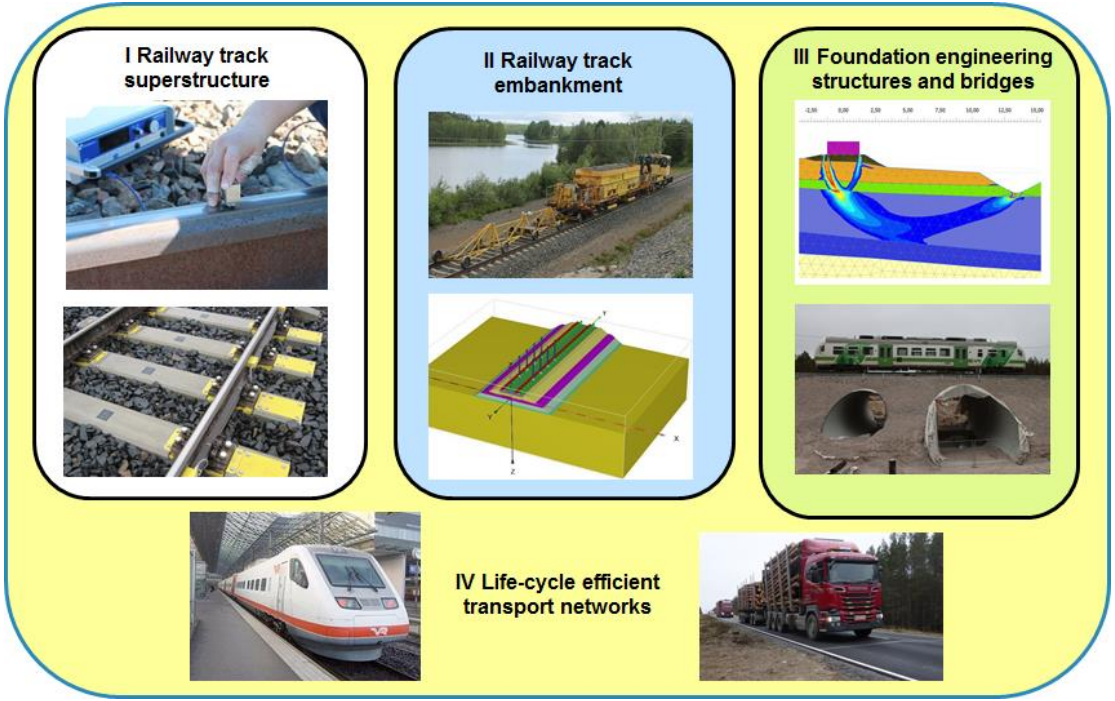
- <u>Project manager:</u> Heikki Luomala
- <u>Professors:</u> Pauli Kolisoja, Tim Länsivaara and Anssi Laaksonen
- <u>Track group:</u> Tommi Rantala, Tiia Loponen, Riku Varis, Juha Latvala, Mikko Sauni, Antti Pelho, Ida Sangi.
- <u>Subsoil group:</u> Juho Mansikkamäki, Juha Selänpää, Mika Knuuti, Bruno DiBuo, Markus Haikola
- <u>Bridge group:</u> Olli Asp, Joonas Tulonen, Petteri Pakkala
- Research assistants



Track research group at TUT

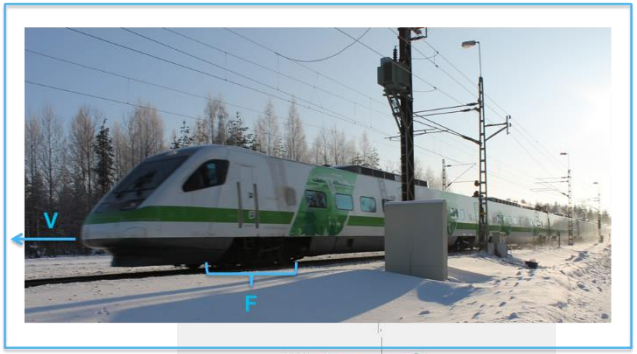


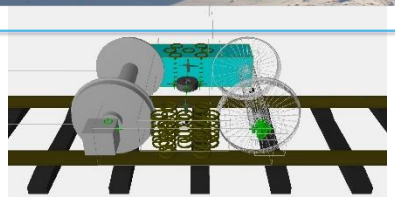
Research program “*Life-cycle cost efficient maintenance of traffic infrastructures (ETEVÄ)*” 2017-2020

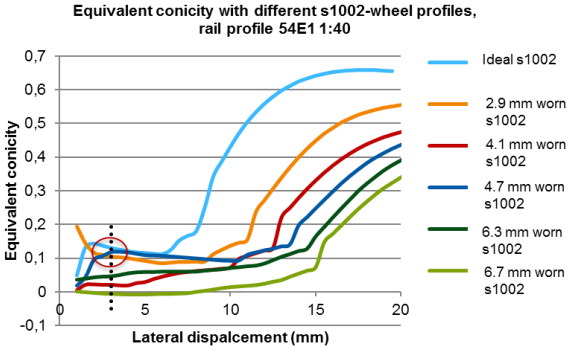


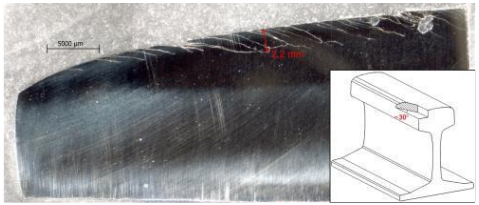
Train-track interaction and its dynamic modelling (Tiia Loponen)

- There is a continuous need to increase train speed and axle loads
- Increasing track loads causes problems to track structure but it also has negative effect on train movements and accelerations
- Research about finding reasonable methods to decrease track loads
- Research about wear, RCF, AHC-profiling, running behaviour, etc.
- *Effects of rail side wearing on running behaviour is in progress*





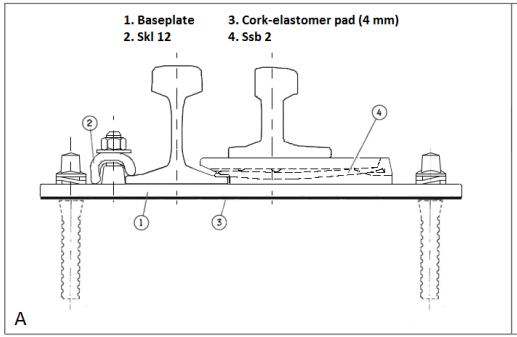




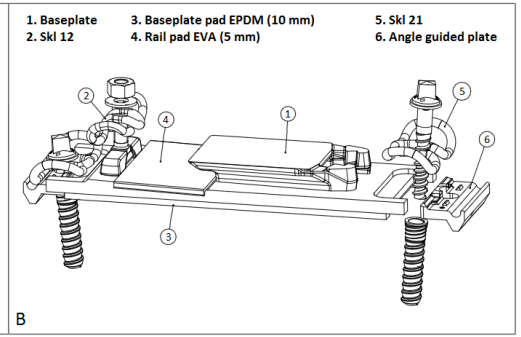
More elastic turnout structures (Riku Varis)

- Development of new more durable and elastic turnout solutions
- Elasticity of the turnout structure was modified with many different components, but the foremost change was to use the proper rail pads in every fastening.
- Other new features was under sleeper pads, angle guided plates, new bearer design and also hollow bearers for actuators etc.

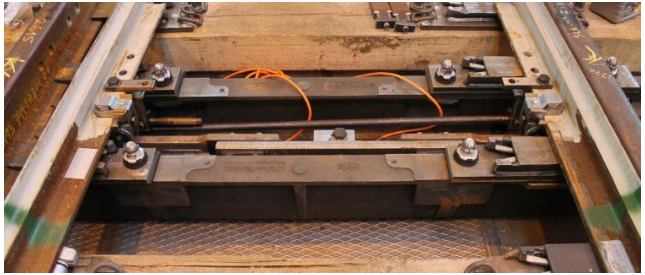
Old fastening



New fastening



Hollow steel bearer



Concrete sleepers replacing wooden sleepers (Tommi Rantala)

- Most of the sleepers are wooden on low volume tracks
- EU-legislation will eventually deny use of creosote oil as impregnating agent
- One solution is to replace wood with concrete
- Concrete sleeper is stiffer
- Individual concrete sleeper may carry more load than it holds

=> study for softer rail pads, wooden sleeper size concrete sleepers and full scale testing

Drainage of railway track (Juha Latvala)

- The role of drainage on geometry problems
  - Lab tests on frost protection layer materials: frost sensitivity, drainability, strength properties, dynamic loading properties
  - Full scale monitoring, 3 sites
  - The effect of drainage improvement on geometry errors

Km 44

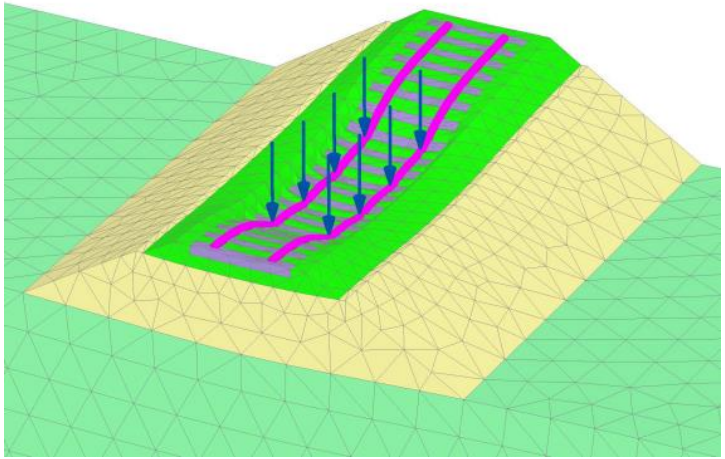
Km 98

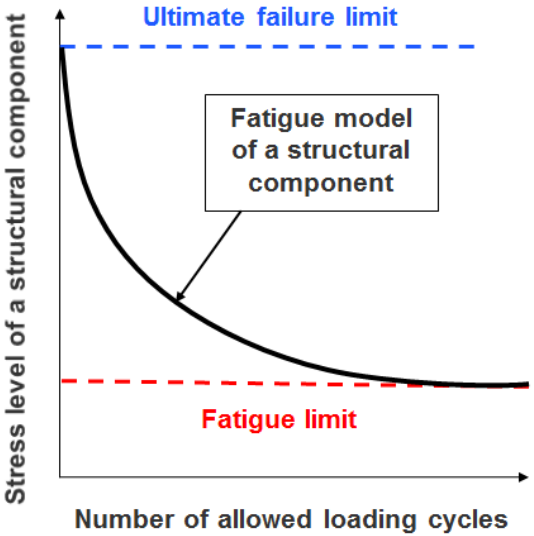
Km 137

Track stiffness measurements and load bearing capacity (Heikki Luomala)

- Development of track condition evaluation methods
- Too low track stiffness causes ballast degradation, embankment widening, fatigue of superstructure components,…
- Too high track stiffness concentrates loads to the superstructure; causes high ballast and sleeper loading
- The measurement device is based on vertical geometry measurement of loaded and unloaded track

Load bearing capacity design of a track

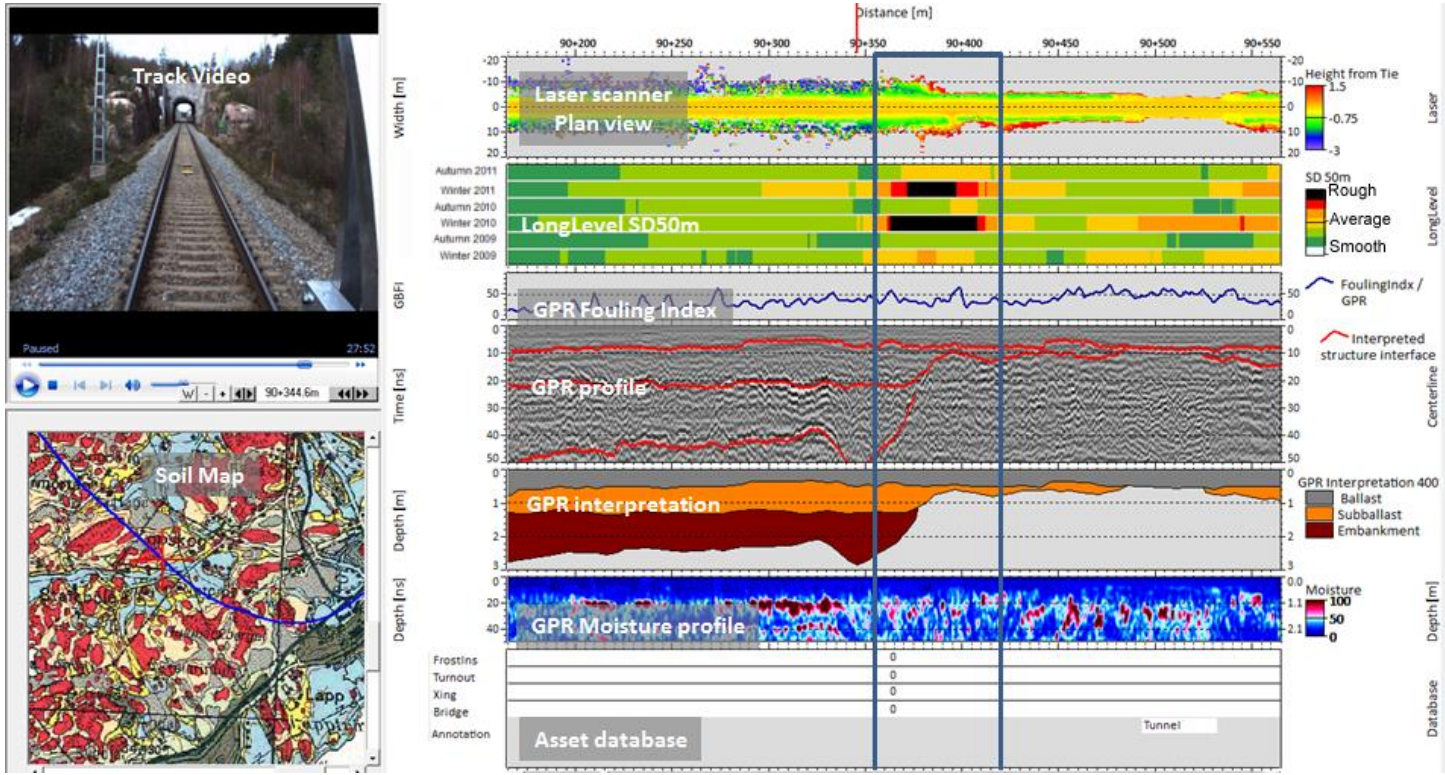




- Whole track 3D-model enables evaluation of mutual interaction of various structural components of track (for example: certain change in subsoil stiffness → magnitude of the change in rail stresses)
- Incorporation of modelled stresses and fatigue models → ”technical life-cycle design” !!

Data mining of big data, better understanding of track behavior (Mikko Sauni)

cooperation with Roadscanners Oy



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Vehicle - track interaction and its dynamic modelling

Tiia Loponen
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Vehicle– track interaction and its dynamic modelling

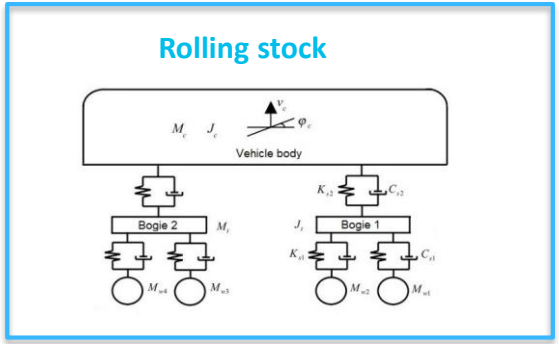
There is a continuous need to increase both train speed and axle load

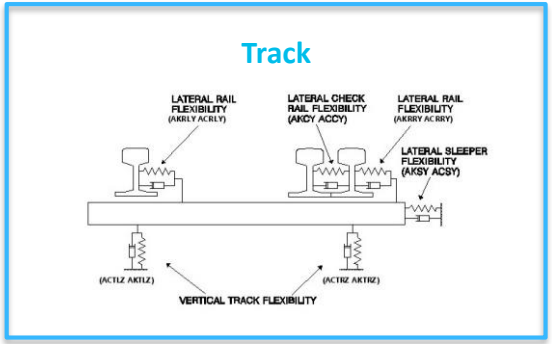
PROBLEM: Increasing track loads causes problems to track structure. It also has negative effect on train movements and accelerations.

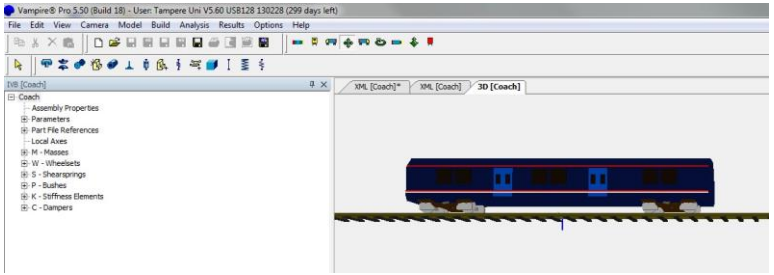
Modelling and simulation is a good method to find reasonable methods to decrease those track loads. Simulations with different vehicle models and track sections clarify the dependency of rail loads on various rolling stock and track parameters.

Vehicle - track interaction and its dynamic modelling

- Simulations with different vehicle models and track sections clarify the dependency of track loads on various rolling stock and track parameters.
- Which methods can decrease track loads?







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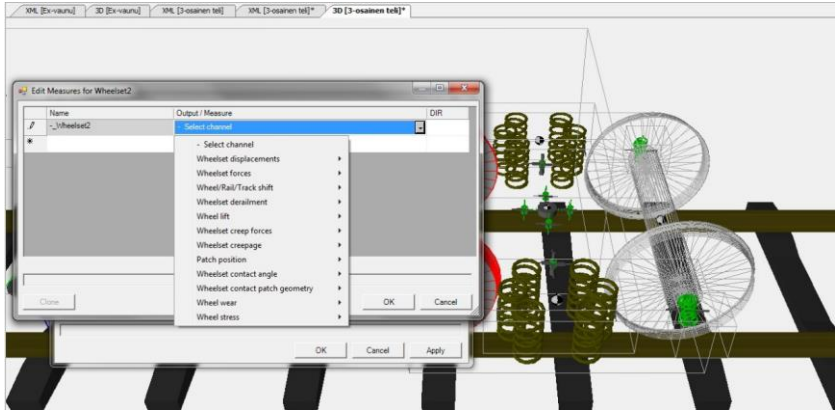
Vehicle-track interaction and its dynamic modelling

- Input (What is the information you need to give?)
  - Wheel and rail profiles
  - Vehicle parameters (mass, stiffness, damping)
  - Track geometry and track irregularities
  - Vehicle speed

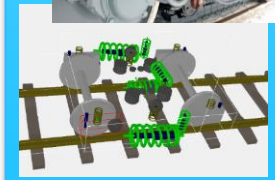
- Output (What is the information you can get?)
  - Displacements, velocities and accelerations in different parts of the vehicle
  - Wheel forces
  - Tgamma –values (wear)
  - Wheel-rail contact information (contact angle, contact patch)
  - …



Vehicle models at TUT

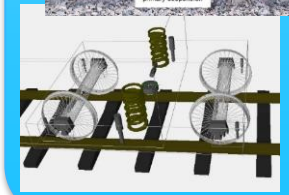
Ed

- Double-decker passenger car
- TB201 bogie
- Secondary suspension: air springs



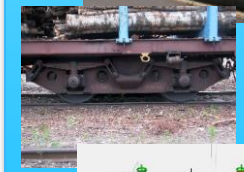
Ex

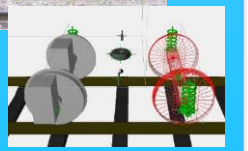
- Single-decker passenger car
- SIG-85 bogie
- Primary and secondary suspension



Sp

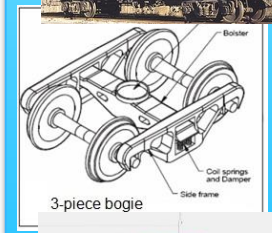
- Finnish raw timber wagon
  - Maximum axle weight 20t
- K14-bogie
  - H-shaped bogie frame
  - Link suspension

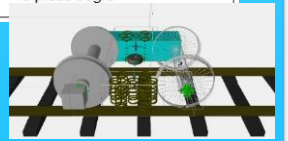




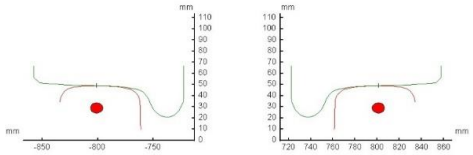
Vok

- Russian freight wagon
  - Maximum axle weight 22,5 t
- 3-piece bogie
  - Bogie: two sideframes and a bolster





Research projects at TUT: vehicle-track interaction



The effect of rail side wear on train derailment risk and the convenience of train passengers (2017 -2019)

- The main target of this project is to examine the effect of various worn rail profiles on equivalent conicity, train movement and track forces. Research method is mainly multibody-based modelling, but also some calculations with Nadal equations will be made.

Verification of railway vehicle models by stationary eigenmode analysis (2015-2016)

- The project was about finding some reasonable methods to verify the rail vehicle models that were previously produced in TUT. It consisted of literature review, rail vehicle measurements and multibody dynamics simulations. The rail vehicle models were improved based on the comparison between measured and simulated values.

Rolling stock – track interaction and its dynamic modelling (2013-2015)

- The aim of this research was to examine the effectiveness of different methods for decreasing track loads. The project included dynamic vehicle simulations focussing on rolling stock– track interaction as well as related track measurements and literature review.

The effect of rail clearance change on train movement and track forces (2013)

- Modelling the effect of rail side wear and the distance between flange contact faces of wheelset on train movement. Both rail side wear and the distance between flange contact faces of the wheelset have an influence on rail clearance, so the main purpose of this project was to examine the effect of rail clearance change on train movement and track forces by means of multibody modelling and simulation.

Detachment of snow from the rolling stock at rail discontinuities (2012)

- Examining the connection between rail discontinuities and the detachment of snow accumulated in rolling stock. The aim was to discover the vibrations generated by different kinds of rail discontinuities in rolling stock, as well as to determine the excitation needed to loosen the accumulated snow from the rolling stock.

Detachment of snow from the rolling stock at rail discontinuities

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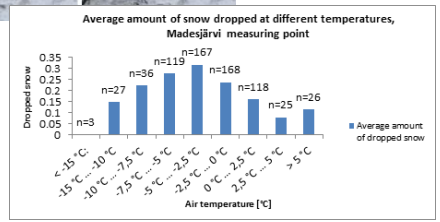

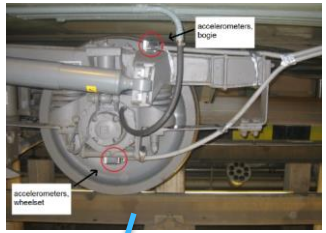

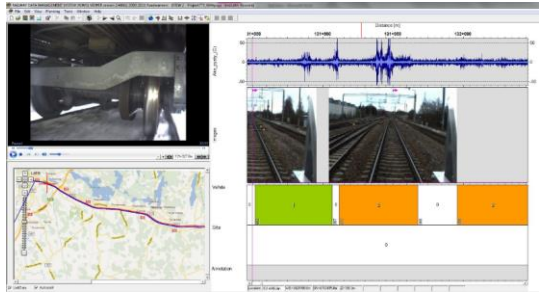

The effect of rail clearance change on train movement and track forces

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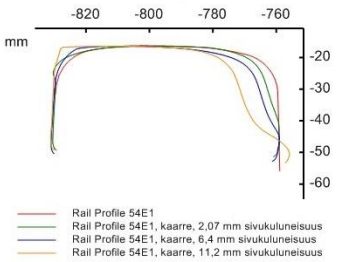
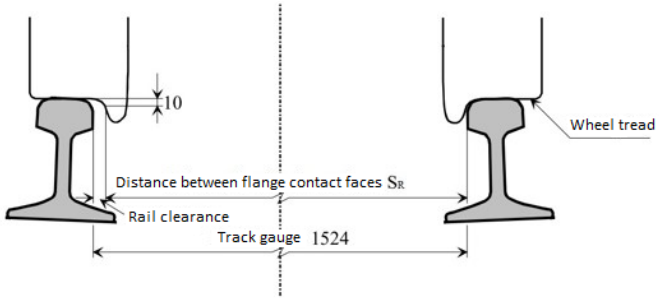
- The distance between flange contact faces S_R
  - 1510 mm (Finland)
  - 1506 mm (Russia)

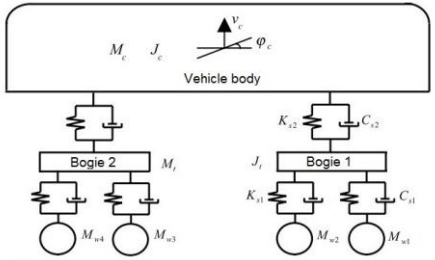


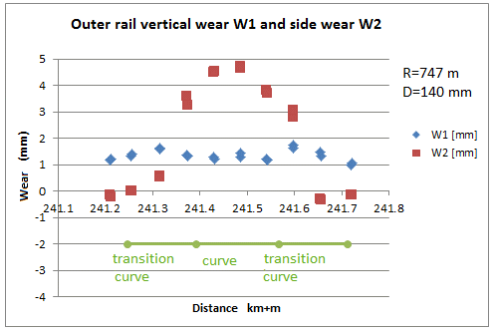


Rolling stock – track interaction and its dynamic modelling

- The effectiveness of different methods for decreasing track loads, especially in curves.
  - Methods related to track: Rail profile, rail cant and gauge widening in curves, rail irregularities, track stiffness and damping…
  - Methods related to vehicle: Wheel profile, axle weight, vehicle speed, bogie rotational resistance…

- This project included dynamic vehicle simulations focussing on rolling stock– track interaction as well as related track measurements and literature review.
- Vehicle models were developed in co-operation with Central Queensland University, Australia

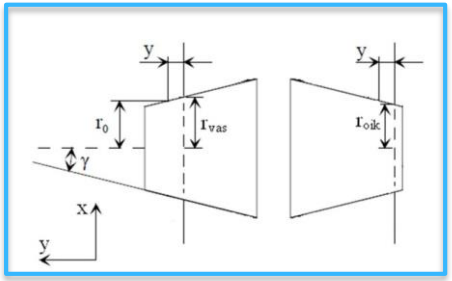


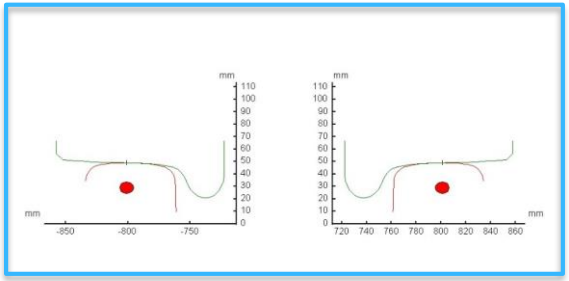


Equivalent conicity

- Equivalent conicity is defined as proportion of difference in rolling radius Δr to wheelset lateral displacement y :

$$\lambda_e = \frac{\Delta r}{2y}$$





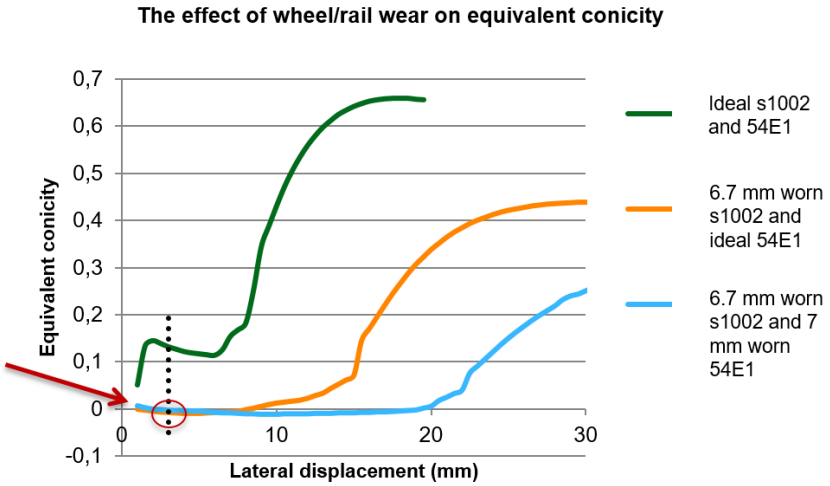
- High conicity may cause wheelset instability, low conicity reduces the guiding properties of the wheelset.
- To maintain running stability, the upper limit of equivalent conicity is defined as 0,3 in Finland (in velocity range 60 km/h – 190 km/h) or 0,25 (in velocities over 190 km/h).
- No lower limit is defined!
- Limit values are usually (in normal situation: G=1524 mm, S_R=1510 mm) defined for wheelset lateral displacement y = 3 mm.

Simulation results: the effect of wheel/rail wear on equivalent conicity

- The effect of wheel flange wear and rail wear on equivalent conicity
  - Ideal wheel profile + ideal rail profile
  - 6.7 mm worn wheel profile + ideal rail profile
  - 6.7 mm worn wheel profile + 7 mm worn rail profile
- Wear also has effect on flangeway clearance
- The values depend on the stage of wear but also on the shape of the worn profile

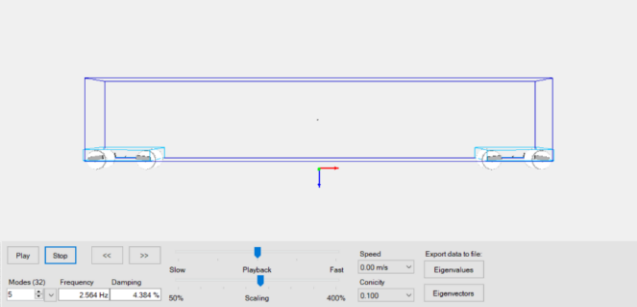
"Worst case"
Equivalent conicity ≈ 0
even in large lateral displacements

No guiding properties!

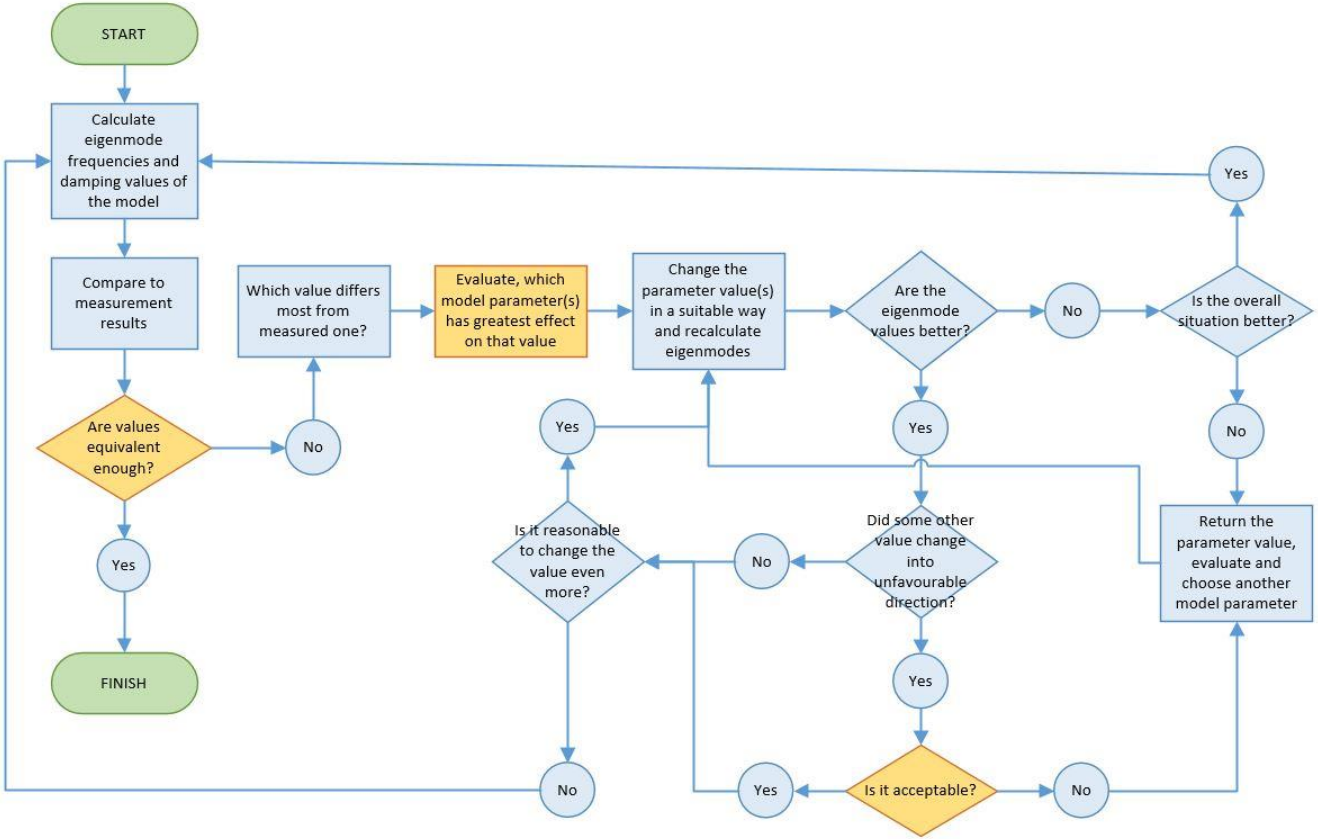


Verification of railway vehicle models by stationary eigenmode analysis

- Validation and verification is highly important part of the model building process
  - The verification method chosen to verify the vehicle models previously produced at TUT, was stationary eigenmode analysis
- Eigenmode analysis was performed to both real vehicles and vehicle models
- In order to get train wagons to measurement use, good co-operation with the owner of the wagons is required
- Measurements are stationary, so the vehicles are standing still while the measurements are done
- Hydraulic actuator is used to produce excitations, responses are measured with accelerometers
  - Eigenmodes of the real vehicles
- Eigenmode analysis tool in simulation software (Vampire Pro)
  - Eigenmodes of the models
- Comparing eigenmode values → improving vehicle model parameters (iterative process)



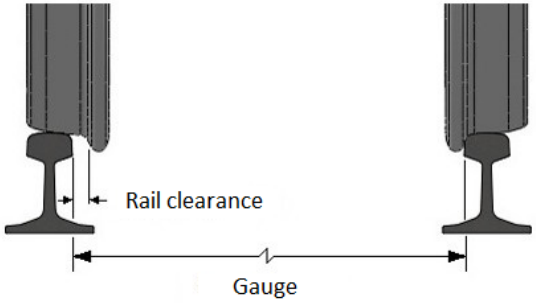
Verification in practice



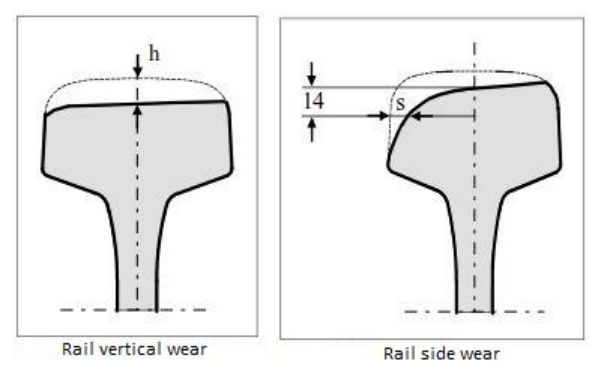
The effect of rail side wear on train derailment risk and the convenience of train passengers

Background: The current rail side wear limits in Finland are pretty conservative. Increasing the limit values would lead to great economical benefits via lower maintenance costs (less need to rail grinding and change). However, rail side wear affects the shape of rail profile and therefore it also has effect on wheel-rail interaction and train movement. What kind of effect?

Target: The main target of this project is to examine the effect of various worn rail profiles on equivalent conicity, train movement (derailment) and track forces. Research method is mainly multibody-based modelling, but also some calculations with Nadal equations will be made. Based on this analysis, the validity of current rail side wear limits in Finland will be evaluated.



Rail side wear limits in Finland



Vehicle speed (km/h)	Rail side wear limit (mm)
Vmax>160	5
120<Vmax<160	7

Combined wear limit H (mm)

$$H = h + \frac{s}{2}$$

Rail	CWR	Other main lines	Side lines
54E1	14	16	18
60E1	14	16	18

Turnout research at TUT
(Special Trackwork)

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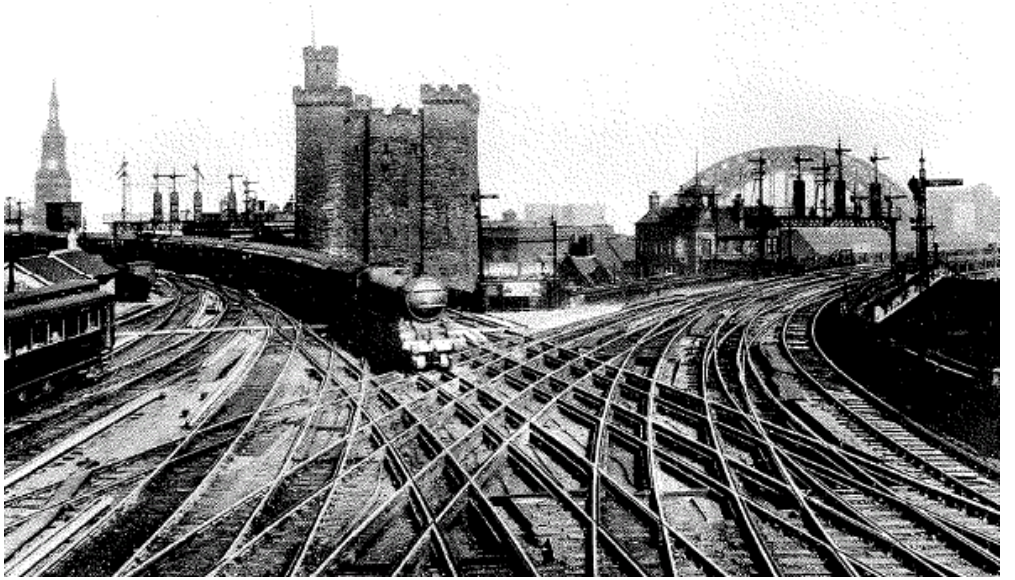
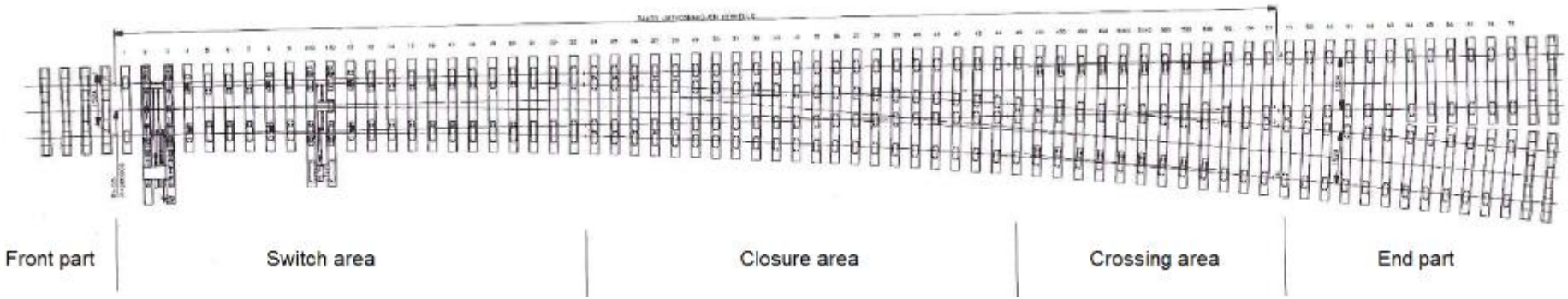
Turnout?

- Turnout is a special structure where the train can be lead to another track.
- Turnout can be also a structure where two tracks intersects each other without possibility to change track.
- Moving from one track to another creates always certain discontinuity points which is the reason why in safety point of view the turnouts is the most critical points in rail network.
- Technically turnout is a special structure which includes all the basic elements (rail, sleepers, fastenings..) but it also includes safety devices. So overall turnout is very complex structure.



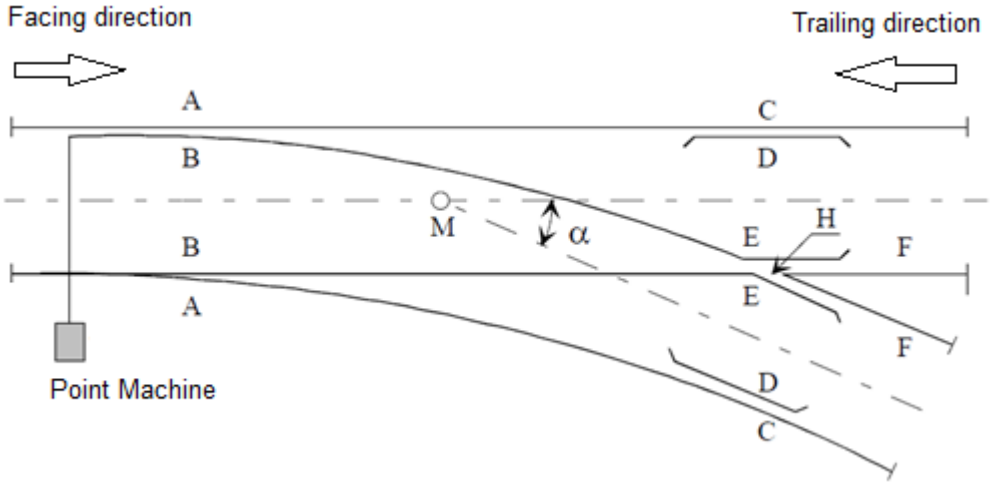
Turnout areas



- Turnout consist of three parts: switch area, closure area and crossing area. Turnout area also includes front and end part where the structure is changed from normal line structure to turnout structure.
- This whole structure can be called ”turnout” or ”switches and crossings”.

BUT *switch* and *turnout* are not the same thing!

Terms



A = stock rail

B = switch blade

C = stock rail

D = check rail (guard rail)

E = wing rail

F = point rail

M = mathematical point of turnout

H = mathematical point of crossing

α = angle of the turnout (normally it is expressed as a crossing ratio for example 1:9)

- Train can use turnout in facing direction (from switch to crossing) or trailing direction (from crossing to switch)
- Turnout is called left (L) or right (R) handed depending which way the diverging route is going when you are facing the turnout.
- Turnout can be changed from one route to another using point machines.

Main topics related to turnouts

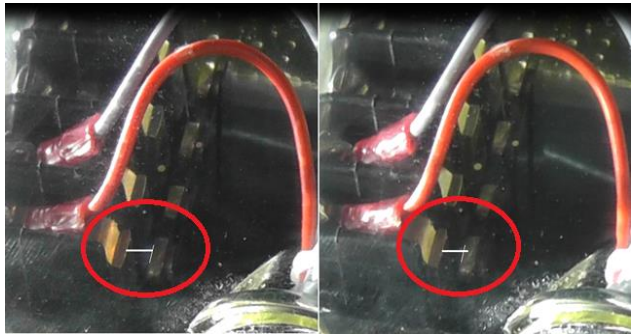
- Rolling stock induced lateral vibration in a railway turnout and its effect on the behavior of toggle spring device (2011 – 2013)
- The complications of vertical stiffness of Finnish railway turnout and its countermeasures (2013 – 2015)
- The functionality of the new Spring setting device (2014)
- Detection failures in signaling system caused by train passages (2014)
- Development of the new elastic turnouts (2014 – Present)
- The effectivity of under sleeper pads in turnouts (2015 – 2017)
- Best installation and tamping practices in turnout areas (2017 – Present)

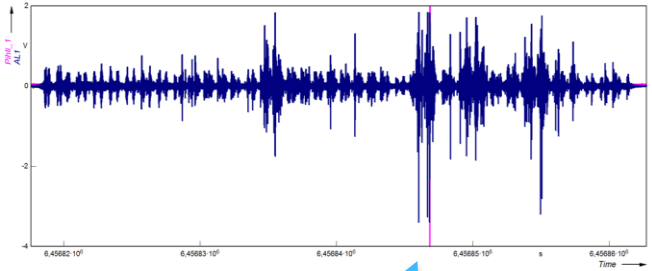
Rolling stock induced lateral vibration in a railway turnout and its effect on the behavior of toggle spring device (2011-2013)

- My Master Thesis project, which aim was to examine, who the rolling stock induced lateral vibration affects to the opening of the point machine. In 2010 we had one turnout derailment at Toijala, which seemed to be caused by this lateral vibration.
- We carried out quite large measurements in that same turnout afterwards, which tried to find out that swich blade vibration during train passage.
- Conclusion was that very minor lateral vibration actually happened in that newly installed turnout.
- Measurements revealed, that the more critical issue is the sufficient flangeway clearence between stock rail and switch blade, which hasn't been decently controlled by the maintenance crew.
- Even the minor contacts between the wheel and the open switch blade in the heel of the turnout can open the point machine in the tip, causing immediate derailment.
- This finding led to situation, where all the point machines, also in the short turnouts, were chanced to non-trailable versions.

Detection failures in signaling system caused by train passages (2014)

- Two major derailment accidents during years 2010 (Toijala) and 2013 (Vammala) awoke the FTA, that our detection devices in turnouts gives a huge amount of short signals, which indicates that the point machine has been temporarily trailed.
- Previously these signals has just been ignored after two succeeded test turns from the traffic control center.
- The reason for these signals has always been a mystery, so this project studied those signals and tried to examined, is there actually some issues related to detection system itself or the vibration, which could compromise the safety.
- This problem was measured in 1:26 –turnout in Hakosilta, which is the most problematic turnout concerning these ”false alarms”.
- Conclusion was, that quite big vibrations were exerted to point machines during train passage and that created actual movement in the detection circuit. In these type of ”high speed” turnout the adjustment values for the detection are quite strict, so it can’t tolerate these kind of vibration.
- The detection system should be redesigned, but at least yet nothing has been changed.

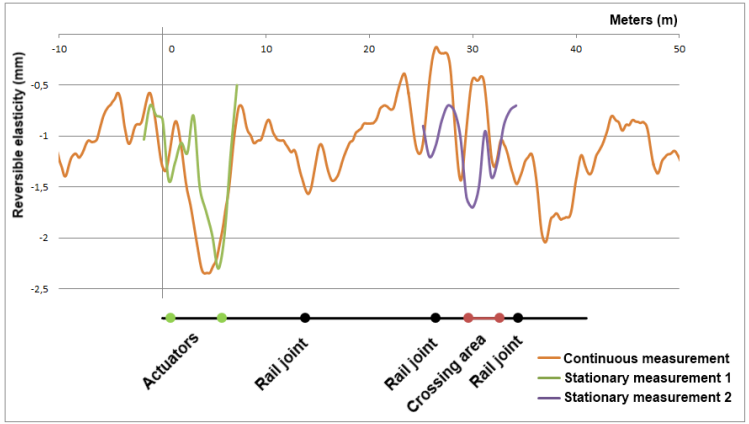


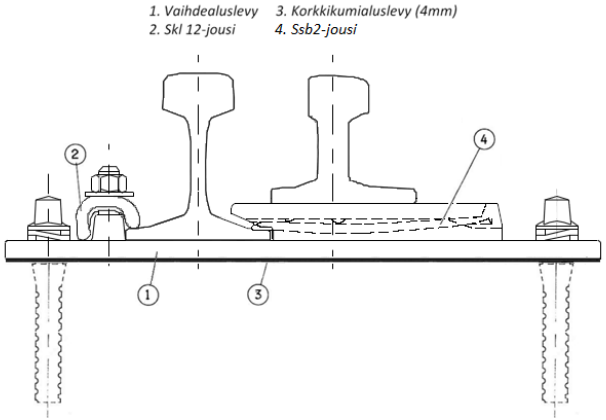


Rapid trailing indication

The complications of vertical stiffness of Finnish railway turnout and its countermeasures (2013-2015)

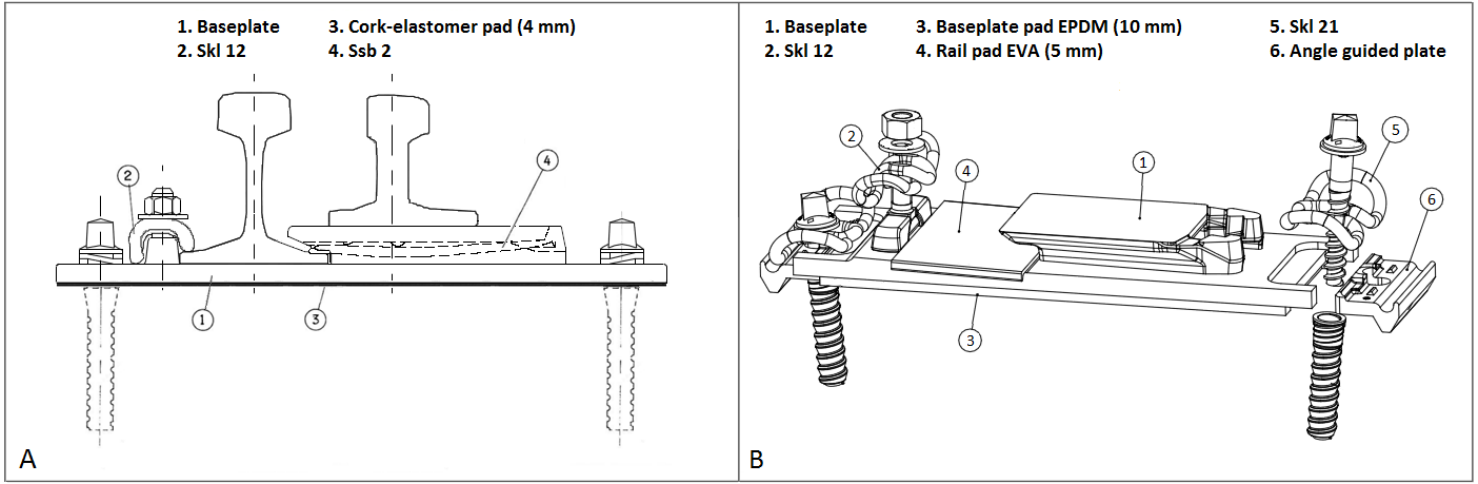
- FTA has been struggled years with the different kinds of failures (broken screws, settlement, crossing deterioration..) in turnouts. So the main target in this project was to clarify the main factors leading to those failures in turnout structure.
- The biggest problems related to vertical stiffness problems, so the focus was aimed mostly to that.
- Studies showed that the current structure is clearly too stiff, which increases the loads in the superstructure and also in substructure.
- Project measured in total 8 different turnouts, which revealed radical stiffness variations between different sections.



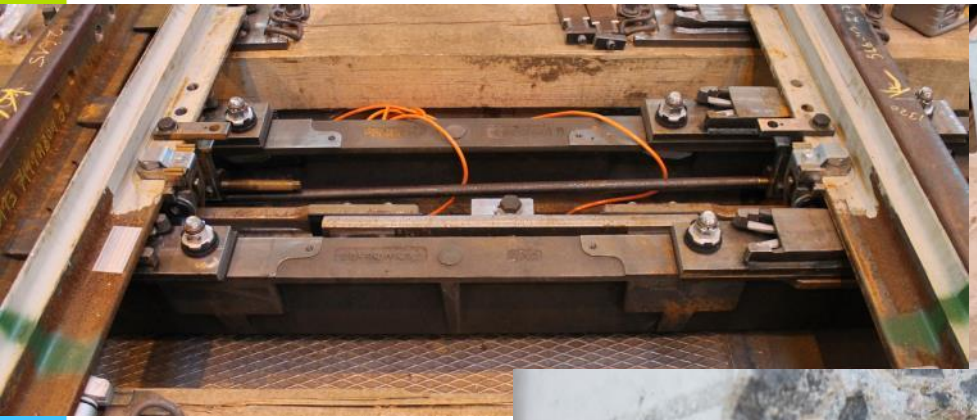


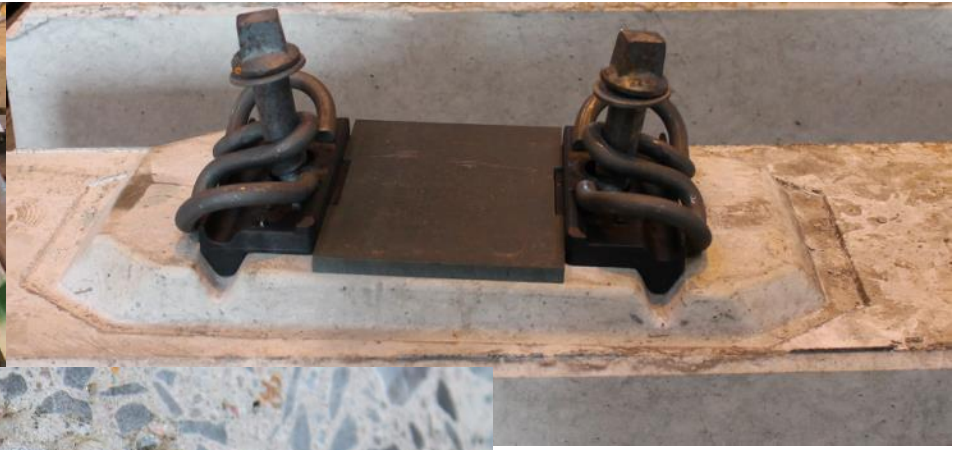
Monitoring of the new elastic turnouts (2014 – Present)

- In 2012 those mentioned stiffness problems led FTA to start developing a new more elastic turnout structure in Finland.
- Structure were changed in many ways, but the most noticeably thing was adding the elastic rail pad also in the switch area and under crossing were no proper pads were previously used.
- Other new features were under sleeper pads, angle-guided plates, new sleeper design and hollow actuator sleepers.
- Short turnouts (1:9 crossing ratio) have been tested in Kouvola since 2014 and long turnouts (1:15,5 crossing ratio) in Oulu since 2016.
- During this year (2018) we have installed about 10 more short elastic turnouts, so that structure has already been moved to production phase.



New features



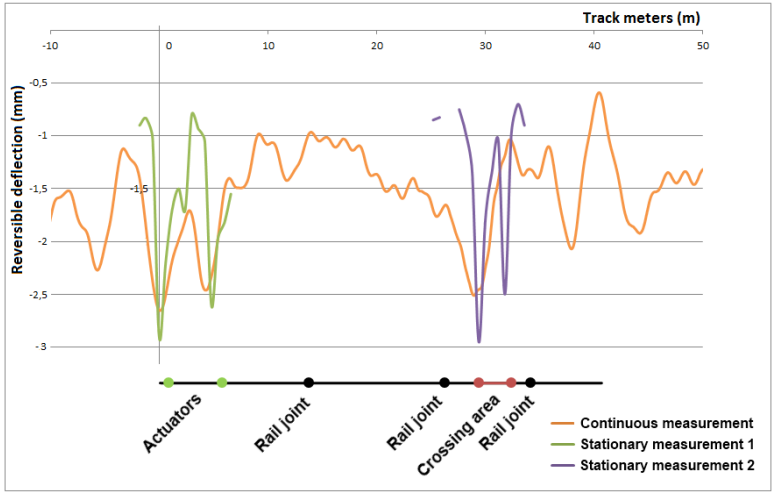


Comparison between old and new structures

- The new structure and the decent tamping procedure leads to situation where the reversible deflection is smoother and there is no single weak points.

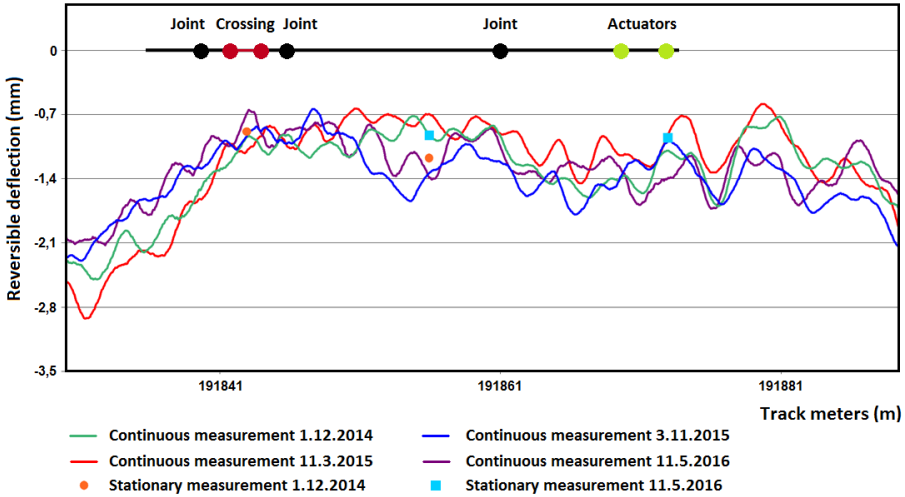
Taavetti V415

(3 years after installation)



Kouvola V059

(2 years after installation)

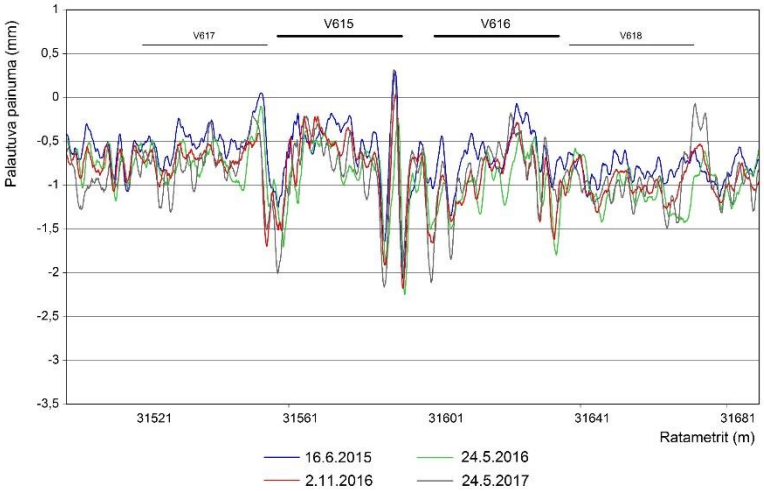


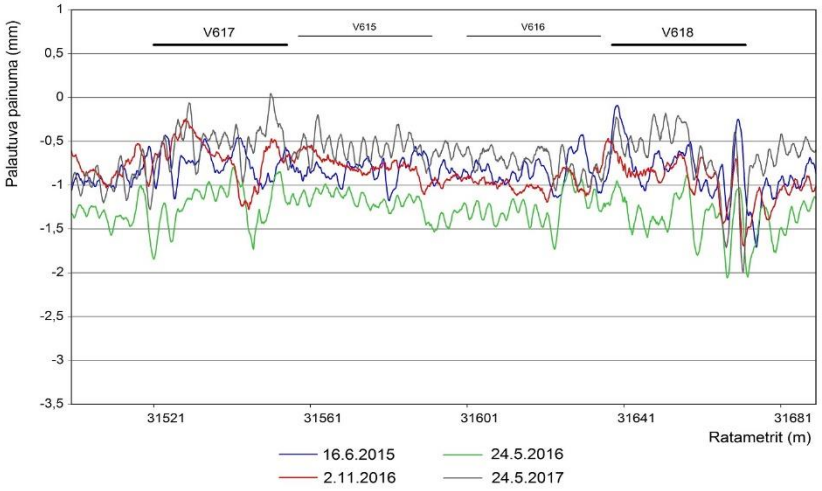
Disadvantages of this new structure

- New structure offers many improvent, but also some issues, what should be still consided in future.
  - Hollow sleepers are really wide (> 400 mm), so the tamping procedure is more difficult and need skills to handle properly. Also some older tamping machines are not able to handle these sleepers, because tamping hacks cannot open so wide.
  - Prototype turnouts included sleeper heating (300 W), but it will need even more to keep the temperature over 0°C, so electricity reservation has to be considered.
  - The adjustment of the outer locking system is more complex and it is not so precise than inner locking system in conventional turnouts.
  - The turnout elements are heavier, so in 1:9-turnouts cranes cannot handle two elements at same time, which has been the normal procedure in conventional turnouts.

The effectivity of under sleeper pads in turnouts (2015-2017)

- As a part of the development work of the turnouts, FTA wanted to install two conventional turnouts equipped with under sleeper pads in the new Ring Rail Line (From Helsinki city centre to Airport).
- As an comparison, also two non-USP turnouts were installed next to these, which has exactly the same traffic.
- Results showed that under sleeper pads evens out the deflection variations in turnout area and reduces the settlement in the long run. But it should be kept in mind that this “long run” starts always again after every tamping. So USP-track has always bigger settlements right after tamping.





Best installation and tamping practices in turnout areas (2017 – Present)

- Tamping is significantly slower and more complicated process in turnout area
- Normal turnout area includes many sections were machinary tamping is not allowed or not sufficient
- During the last years, FTA have had concerns that the expertise of the tamping has disappeared in the field and too many different methods are being used between various maintenance companies
- FTA would like to create their own tamping regulations for turnouts, which would standardizes the procedure
- This project tries to find the best practices from the field and that way give recommendations, which will hopefully help to create those regulations in future.

Thank you for your interest!

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