RATA 2023

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Track-friendliness of freight wagons on the Finnish Rail Network

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Finnish Transport Infrastructure Agency

The Project!

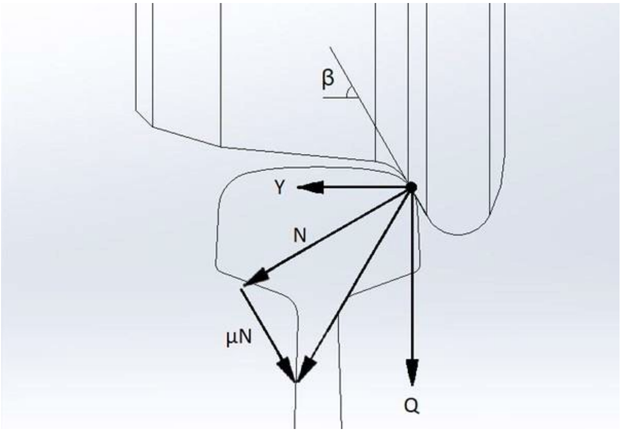
- Supported by the **Finnish Transport Infrastructure Agency**.
- The aim of the project is to answer the question:

How can the track-friendliness of different freight wagons be evaluated?

- This study will focus on understanding the **‘dynamic behaviour’** of the freight wagon bogies running in Finland.
- This study is the first part of a larger project, where in time the project develops different **assessment methods** to judge the performance of the freight wagon bogies.

Literature review → **Critical Parameters** → **Simulations**

What does track-friendliness mean?



The need for ‘heterogenous’ traffic calls for bogies to be more track-friendly!

*A **track-friendly** bogie:*

~ *produces low/moderate forces on the track*;

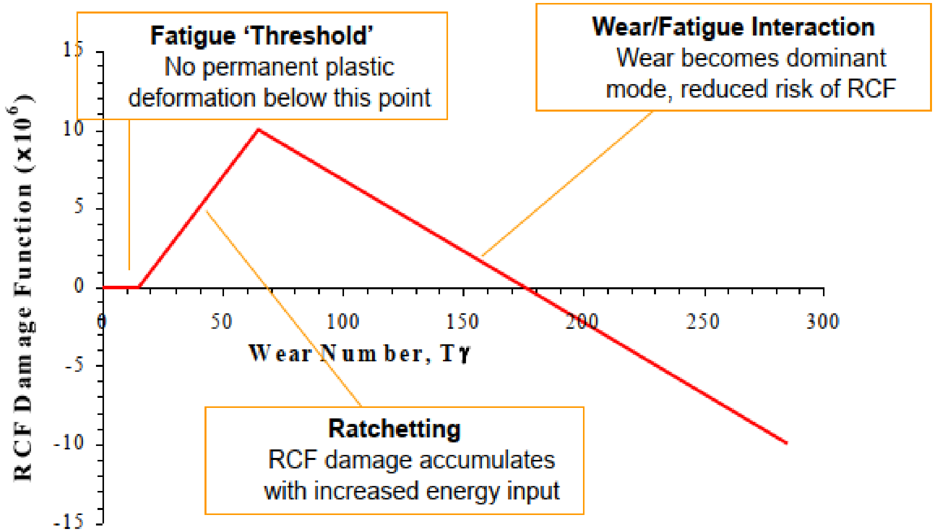
~ *produces low abrasive wear or rolling contact fatigue on the track*;

~ *should be able to run on a ‘non-perfect’ track* (i.e., with significant track irregularities);

Such a bogie will cause *minimal track deterioration*; incur *less maintenance* and renewal activities; *reduce the costs* associated to it; and result in *favorable operating vehicle conditions*.

Assessment of track-friendliness?

- The **contact patch frictional energy**, T_γ(or T-gamma), is calculated from lateral and longitudinal creep forces, T_x and T_y, and creepages, γ_x and γ_y, using the formula: $T\gamma = T_x \gamma_x + T_y \gamma_y$
- Such assessment is carried out in terms of wear and damage to the rails. The **lower the T-gamma value, the lower the damage**.
- It is assumed that the
  - **fatigue initiates at 15 N (J/m)** and reaches **its peak at 65 N.**
  - After this limit, the **wear risk increases and becomes equal to RCF at 175 N**, but it dominates with the further increase in Tγ levels (> 175 N)
- In addition to this **wheel-rail forces**, like the axle load and lateral forces help with the assessment of track-friendliness.



What are the freight bogies running on the network?

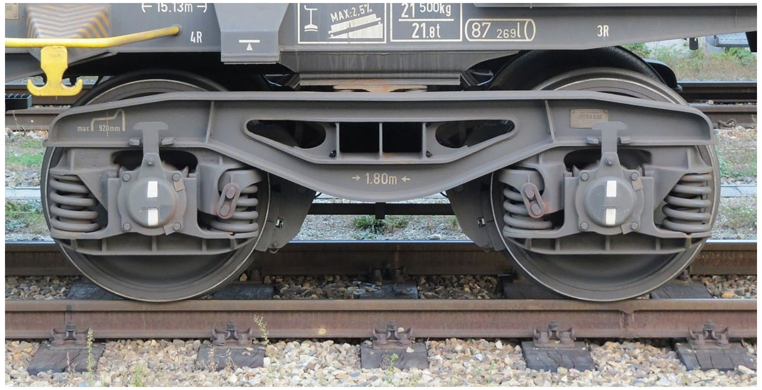
Two-axle wagon

K16 (G type bogie)

K14 (G type bogie)

K17 bogie

Three-piece 18-100 bogie

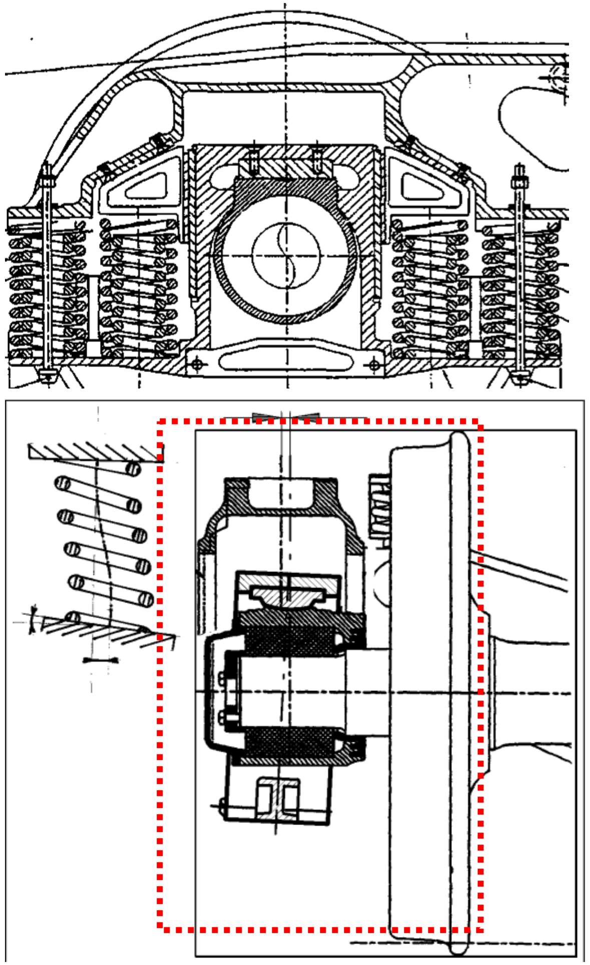


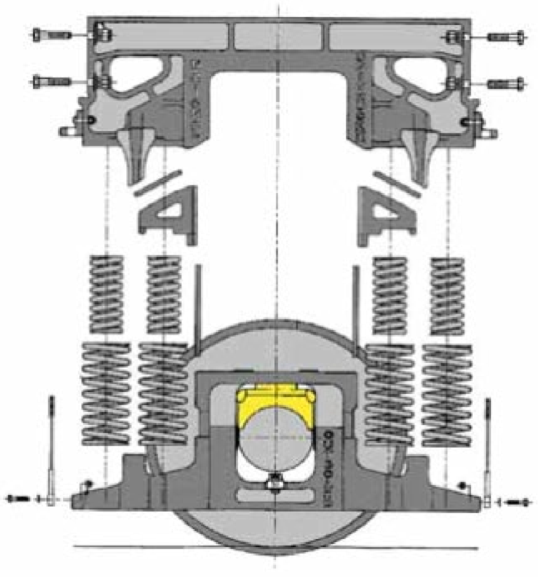
Y25 bogie

From Literature (1/3)

K17 Bogie

- Axle Motion Bogies designed to meet the 25-tonne axle load requirement in Finland.
- The seating arrangement of the saddle onto the wheelsets impose some **degrees of freedom, laterally**.
- The amount of lateral play is dependent on by the bending stiffness and axial stiffness of the springs.
- Lateral play is about **20-22.5 mm** and **9-9.5 mm** in the longitudinal direction.





Ref: Bohumil V. & Ondrouch J.

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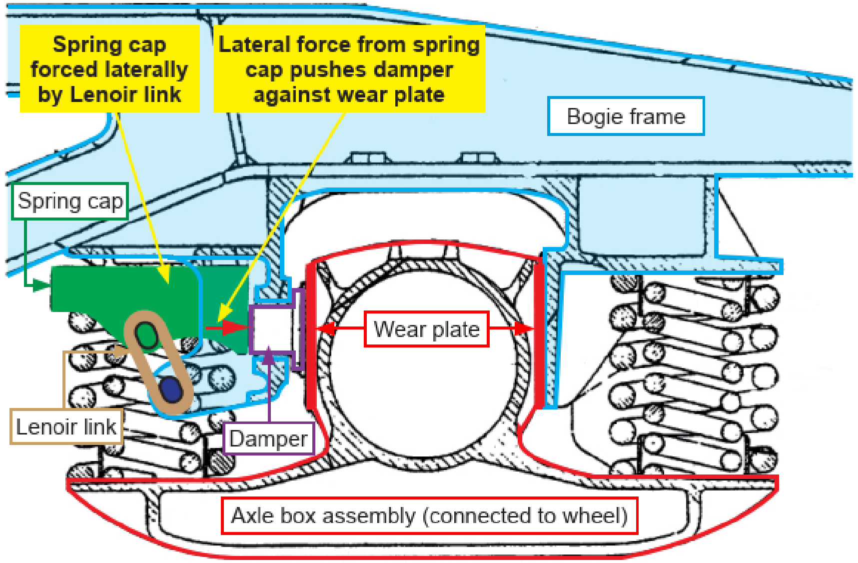
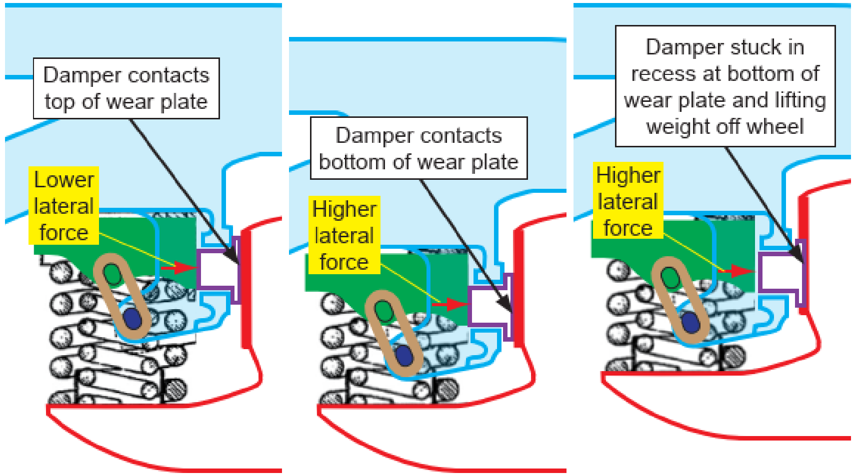
Y25 Bogie:

- **Outer spring Tare conditions** and **Inner spring Laden conditions**, making the suspension of the vehicle **stiffer**.
- Part of the vertical force is applied via **‘Lenoir’ link** causing the spring cap to push a damper onto a wear plate on the axle-box.
- The frictional damping is load dependent.
- Some form of damping is provided by the action of side bearers and the central pivot joint.
- Lateral play is about **10 mm** (half of Axle motion bogie) and **4 mm** in the longitudinal direction.





Ref: RAIB

Three-piece bogie:

- Two separate **side frames that rest directly on the axle boxes through adaptors** that allow only rotational freedom.
- Damping is provided by the **wedge friction dampers** working in vertical and lateral directions.
- Important parameter that influence curving is the total **longitudinal clearance between the axle box and the side frame**.
- Satisfactory curving in the three-piece 18-100 bogie, the clearance should compose **at least 8 mm**, maximum at 15-20 mm.

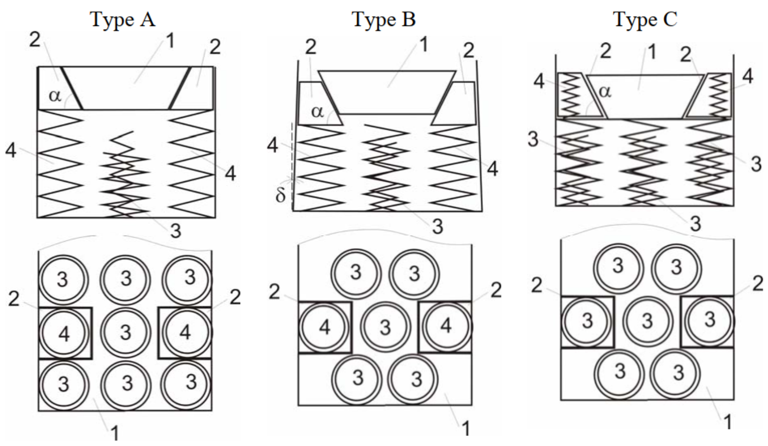
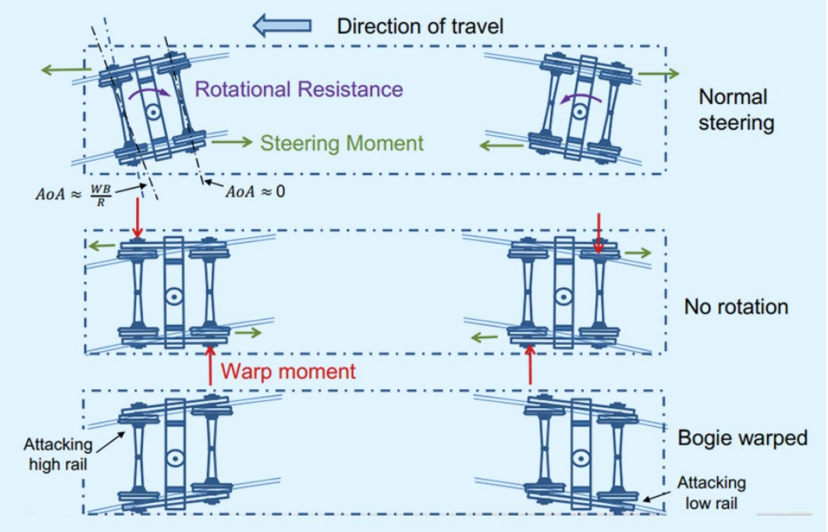


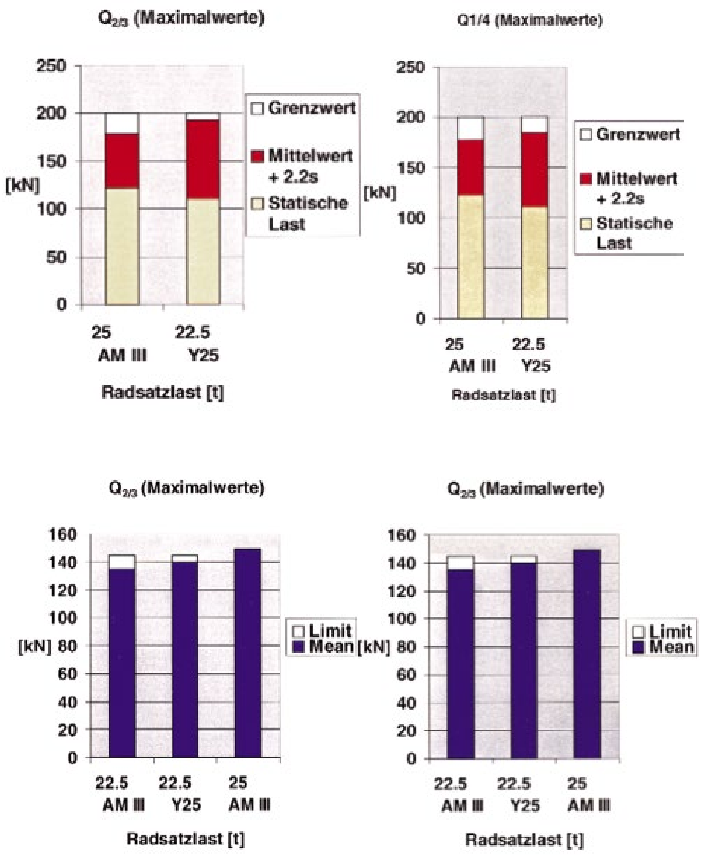
Fig. 1 Designs of central suspension shown in zero gravity condition: 1 – bolster, 2 – wedge, 3 – load springs, 4 – wedge springs

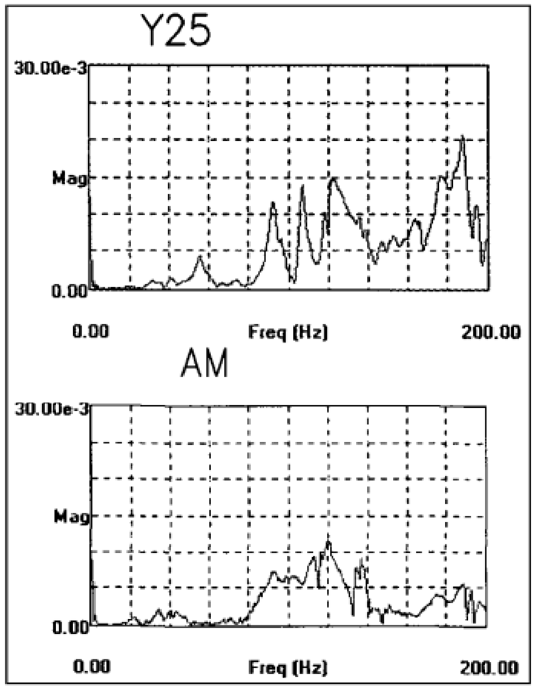


Ref: Orlova A; Boronenko Y.

Inference from literature:

- K17 bogie had 7 natural frequencies whereas **Y25 had 21**!!
- Sharp resonance peaks are seen for the **Y25 bogie indicating lower damping**.
- AM III bogie never reach the limit value of 200 kN for the vertical wheel force Q.
- AM III bogie also fulfils for heavier wagons with a wheelset load of 25 t a limit value of 78 kN for the lateral force, especially in curved tracks.
- The Axle Motion III also fulfils the derailment criterion Y/Q < 0.8.





Ref: Muller C

Inference from literature:

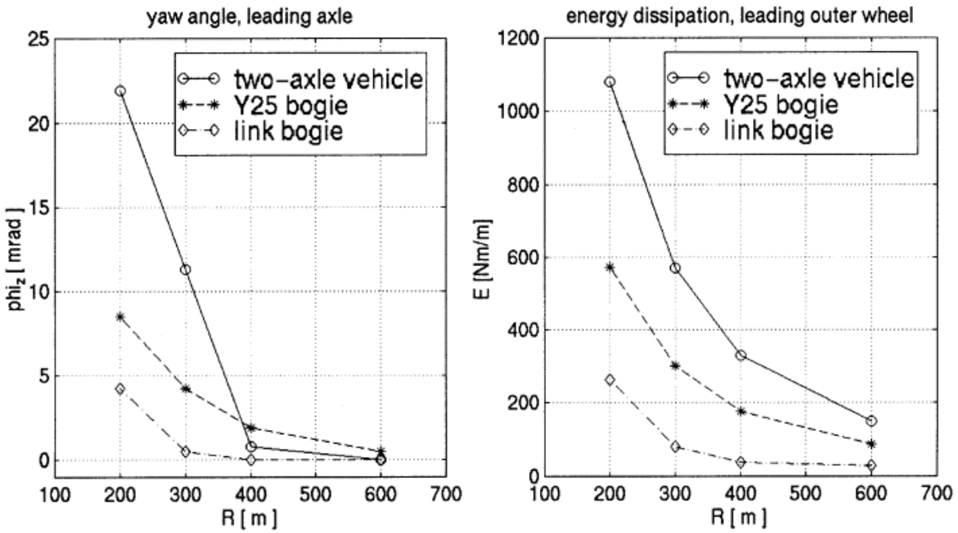
Curving performance of Y25 bogie is poor!

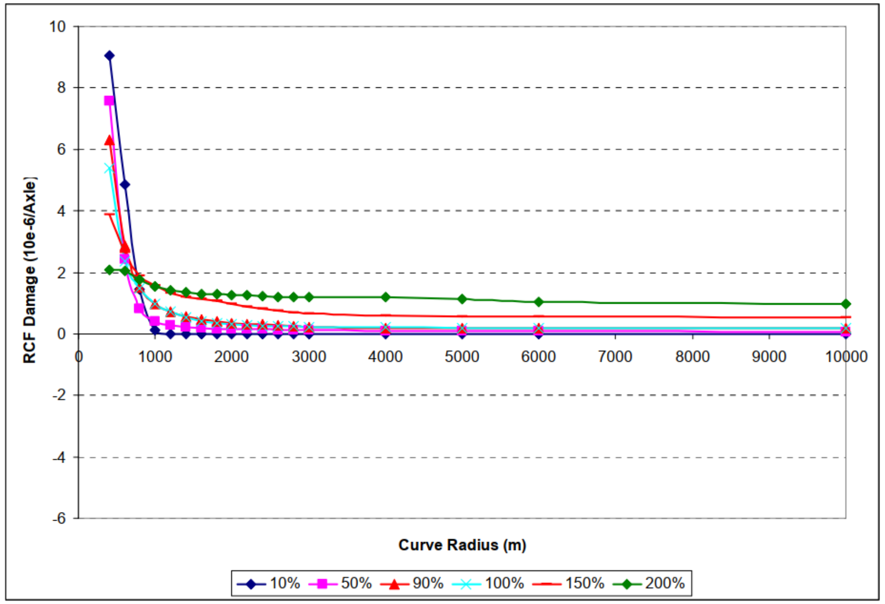
Wheelset 1	Curve		Yaw angles vrs. Track ref. frame[mrad]		
Load Condition	Radius	Curvature (Ψ_0)	Steady-state(Ψ)	Peak	Ψ/Ψ_0
	[m]	[mrad]	[mrad]	[mrad]	[%]
Laden	200	5	4.1	4.1	82 %
Laden	400	2.5	0.9	1.4	36 %
Laden	1000	1	0.3	0.7	30 %
Tare	200	5	4.9	4.9	98 %

Table 14: Level III curving simulation - Wheelset Yaw angle.

LOAD	Curve radius	Speed	ANC	Y/Q
	[m]	[m/s]	[m/s^2]	[/]
Tare	200	7.5	0.6	0.15
Tare	100	11	0.6	0.20
Tare	60	6	0.6	0.43
Laden	60	6	0.6	0.13

Table 12: Maximum Y/Q value obtained with the Level 1 contact model.



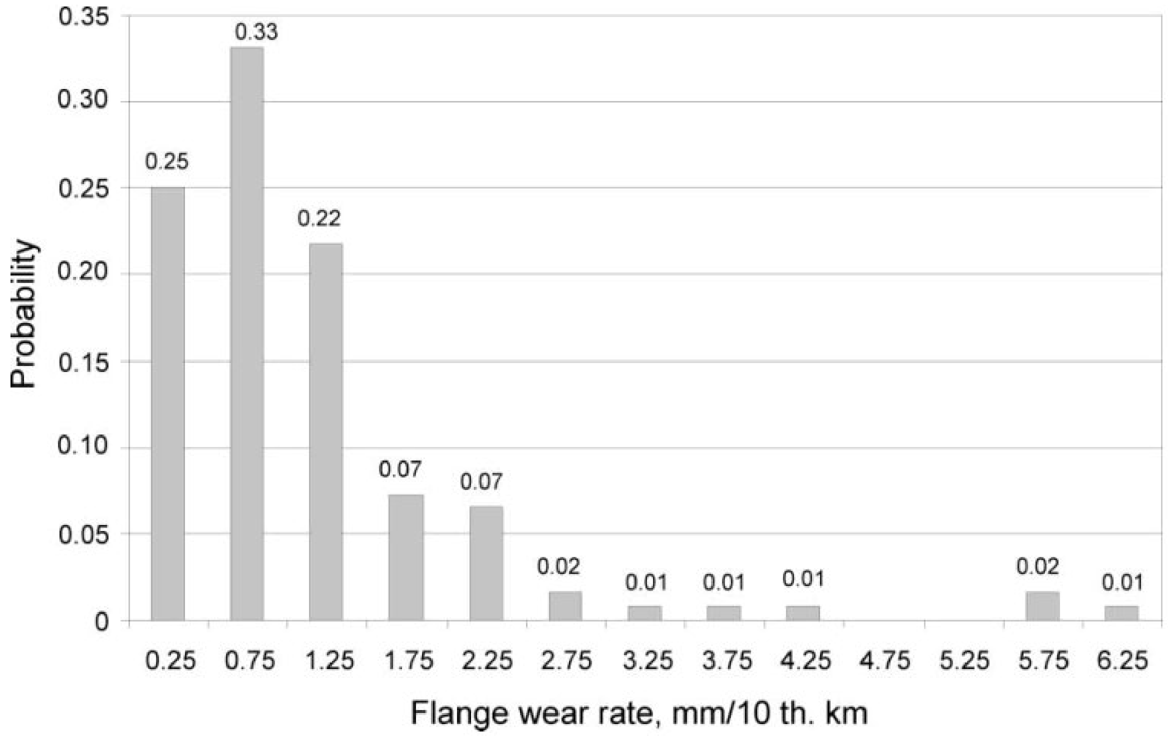


Ref: Stichel S; Bosso N; Tunna J.

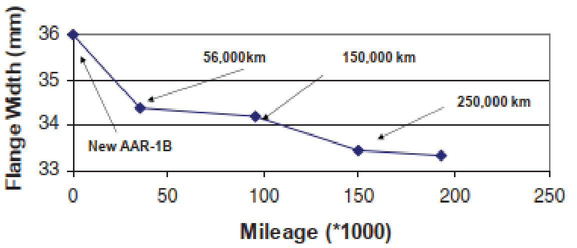
Figure 16. Effect of Track Quality on RCF Damage – FSA with Y25 Bogies

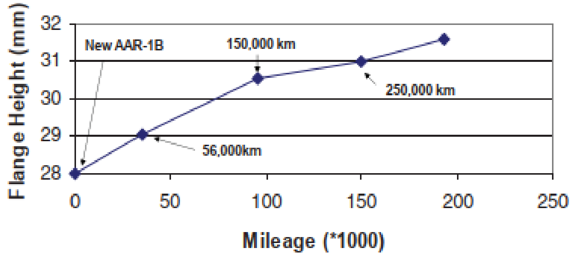
Inference from literature:

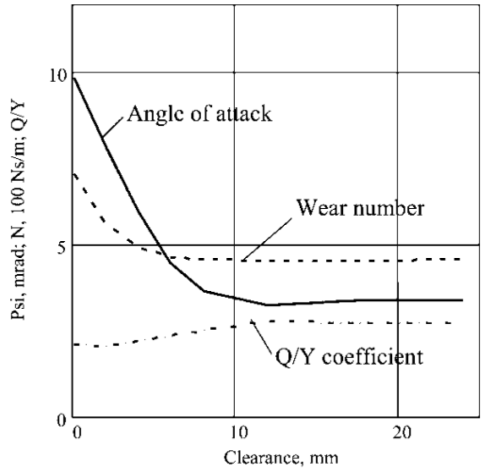
Higher wear rates by flanging in three-piece bogie



Ref: Orlova A; Boronenko Y; Wilson N.





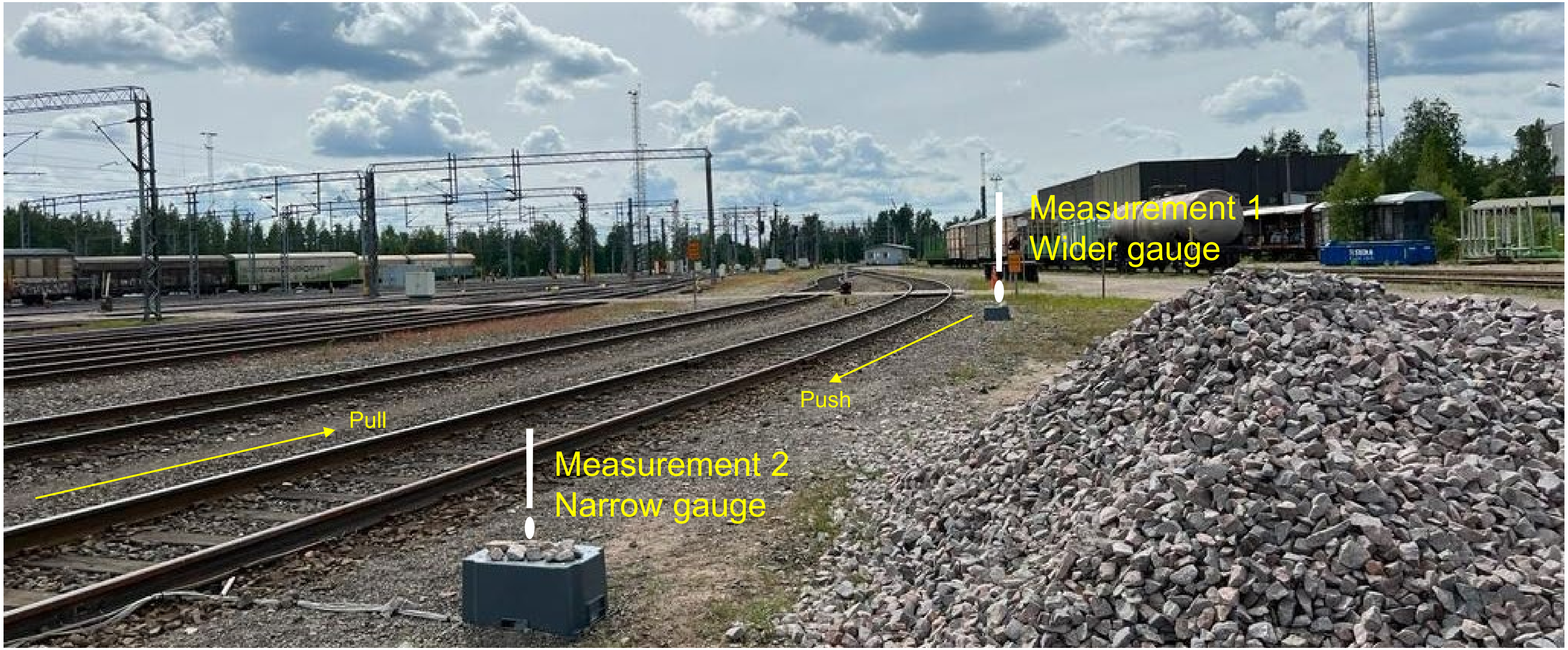


Seventy percent of gondolas have flange wear rate below **1.25 mm/10,000 km**.
Three-piece bogies have caused **more side wear in rails** at small and medium radius curves in Finland.

Field Measurements (2/3)

- On-site tests have also been carried out recently near **Kouvola** for different freight wagons (loaded and unloaded).
- The dynamic behaviour of the wagons was studied in a tight curve of radius 200m.
- Vertical and Lateral wheel-rail forces; Longitudinal forces; Angle of attack of all the wheels; and the wheel profiles were measured.
- Such on-site tests provide valuable real time data on the performance of the bogies.

Measurement Site: Kouvola Railway Yard (R200 m curve)



Results and interpretation: Freight Wagons (1/2)

- Higher lateral forces for the **loaded wagons**;
- Y/Q Coefficient within limits;
- K17 bogie behaviour **unusual**! (while measuring the wheel profile the wheels were significantly worn out!!)

A. Lateral force of the leading wheelset of a freight wagon negotiating a curve:

	5 km/h	15 km/h	25 km/h	35 km/h
18-100	54.37	56.37	62.29	62.43
$K16_{UL}$	4.35	4.59	7.06	8.04
2 $Axle_{UL}$	10.72	9.13	13.4	13.66
$K14_{UL}$	5.19	4.49	6.21	8.12
$K17_{UL}$	20.25	20.14	19.11	17.21
$K17_{L}$	46.79	44.15	44.03	45.38
$K16_{L}$	13.47	14.63	22.08	34.45
2 $Axle_{L}$	20.93	26.58	30.48	32.98

Old curve – Summer measurement 2022

	5 km/h	15 km/h	25 km/h	35 km/h
18-100	53.98	63.22	67.33	69.75
$K16_{UL}$	12.96	11.11	14.86	15.58
2 $Axle_{UL}$	16.45	13.1	17.61	19.99
$K14_{UL}$	4.37	2.69	4.97	7.49
$K17_{UL}$	22.76	25.44	25.87	28
$K17_{L}$	53.29	62.44	67.7	68.53
$K16_{L}$	56.69	59.83	63.7	75.98
2 $Axle_{L}$	51.45	38.05	35.78	48.88

New curve – Summer measurement 2022

B. Y/Q ratio of the leading wheelset of a freight wagon negotiating a curve:

	5 km/h	15 km/h	25 km/h	35 km/h
18-100	0.51	0.51	0.53	0.48
$K16_{UL}$	0.13	0.13	0.20	0.23
2 $Axle_{UL}$	0.32	0.26	0.38	0.40
$K14_{UL}$	0.18	0.16	0.22	0.29
$K17_{UL}$	0.55	0.53	0.50	0.43
$K17_{L}$	0.45	0.41	0.40	0.40
$K16_{L}$	0.12	0.13	0.18	0.28
2 $Axle_{L}$	0.21	0.27	0.30	0.32

Old curve – Summer measurement 2022

	5 km/h	15 km/h	25 km/h	35 km/h
18-100	0.46	0.51	0.51	0.51
$K16_{UL}$	0.36	0.30	0.43	0.44
2 $Axle_{UL}$	0.47	0.38	0.48	0.55
$K14_{UL}$	0.15	0.10	0.18	0.27
$K17_{UL}$	0.63	0.68	0.67	0.71
$K17_{L}$	0.44	0.52	0.55	0.55
$K16_{L}$	0.45	0.47	0.50	0.56
2 $Axle_{L}$	0.52	0.36	0.34	0.44

New curve – Summer measurement 2022

Worn out profile of the K17 bogie (empty).

Old Curve: Measurement site 1; New Curve: Measurement site 2

Results and interpretation: Freight Wagons (2/2)

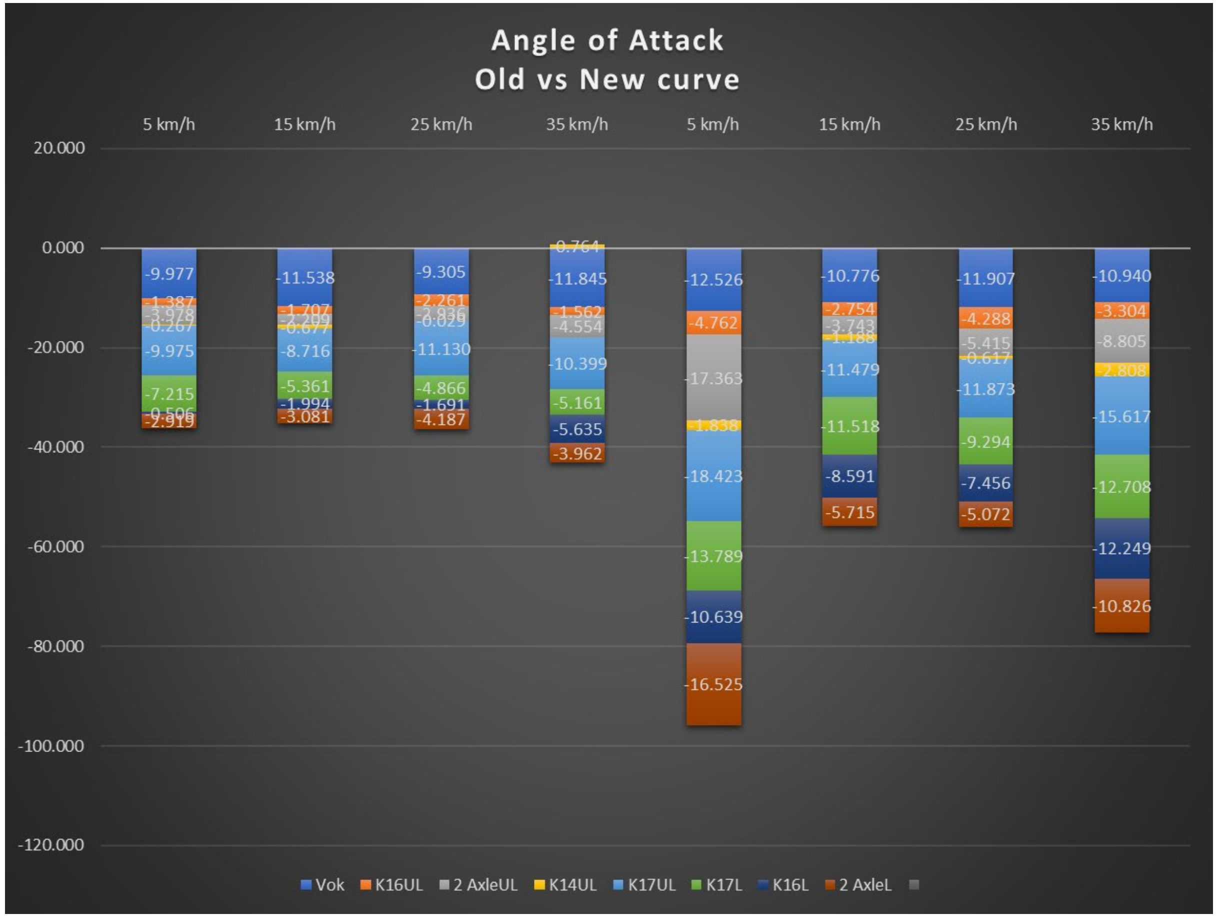
C. Angle of attack of the leading wheelset of a freight wagon negotiating a curve:

	5 km/h	15 km/h	25 km/h	35 km/h
18-100	-9.977	-11.538	-9.305	-11.845
$K16_{UL}$	-1.387	-1.707	-2.261	-1.562
$2\ Axle_{UL}$	-3.978	-2.209	-2.936	-4.554
$K14_{UL}$	-0.267	-0.677	-0.029	0.764
$K17_{UL}$	-9.975	-8.716	-11.130	-10.399
$K17_{L}$	-7.215	-5.361	-4.866	-5.161
$K16_{L}$	-0.506	-1.994	-1.691	-5.635
$2\ Axle_{L}$	-2.919	-3.081	-4.187	-3.962

Old curve – Summer measurement 2022

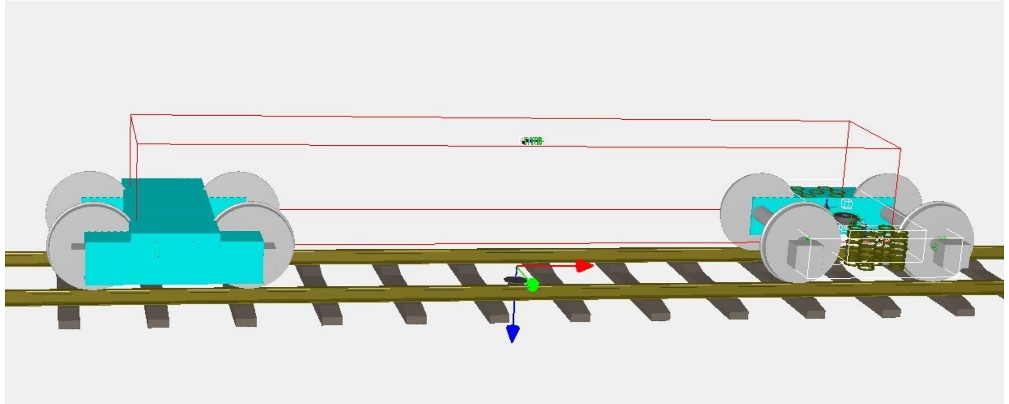
	5 km/h	15 km/h	25 km/h	35 km/h
18-100	-12.526	-10.776	-11.907	-10.940
$K16_{UL}$	-4.762	-2.754	-4.288	-3.304
$2\ Axle_{UL}$	-17.363	-3.743	-5.415	-8.805
$K14_{UL}$	-1.838	-1.188	-0.617	-2.808
$K17_{UL}$	-18.423	-11.479	-11.873	-15.617
$K17_{L}$	-13.789	-11.518	-9.294	-12.708
$K16_{L}$	-10.639	-8.591	-7.456	-12.249
$2\ Axle_{L}$	-16.525	-5.715	-5.072	-10.826

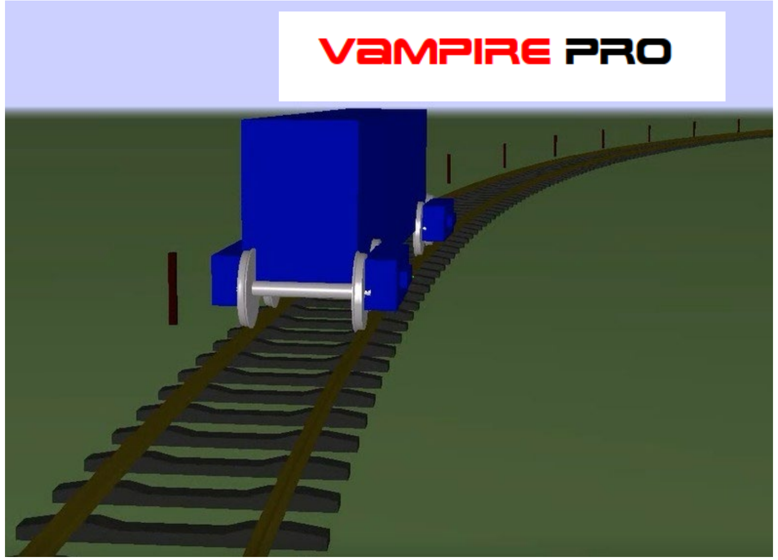
New curve – Summer measurement 2022



Multi-body system Simulations (MBS) [3/3]

- ➢ Simulations carried on Vampire Pro MBS software;
- ➢ Two available freight models – K14 and 18-100 bogie;
- ➢ Run different scenarios like:
    - ➢ Effect of curve radius at different speeds;
    - ➢ Effect of axle load and its dynamics;
    - ➢ Track irregularities (includes gauge widening).





Colours in graphs – Speeds 25 km/h: Red; 35 km/h: Green; 45 km/h: Blue; 55 km/h: Yellow.

Good track: transverse standard deviation – 1.42 mm & Vertical standard deviation – 2.39 mm

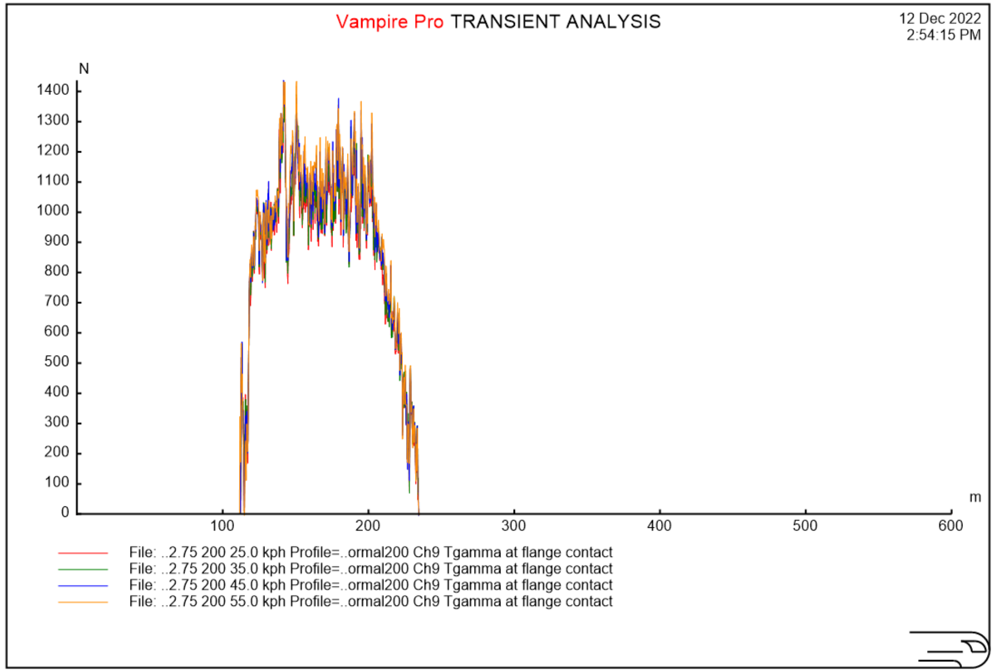
R200m

1. T-gamma value at flange contact

Axle Load

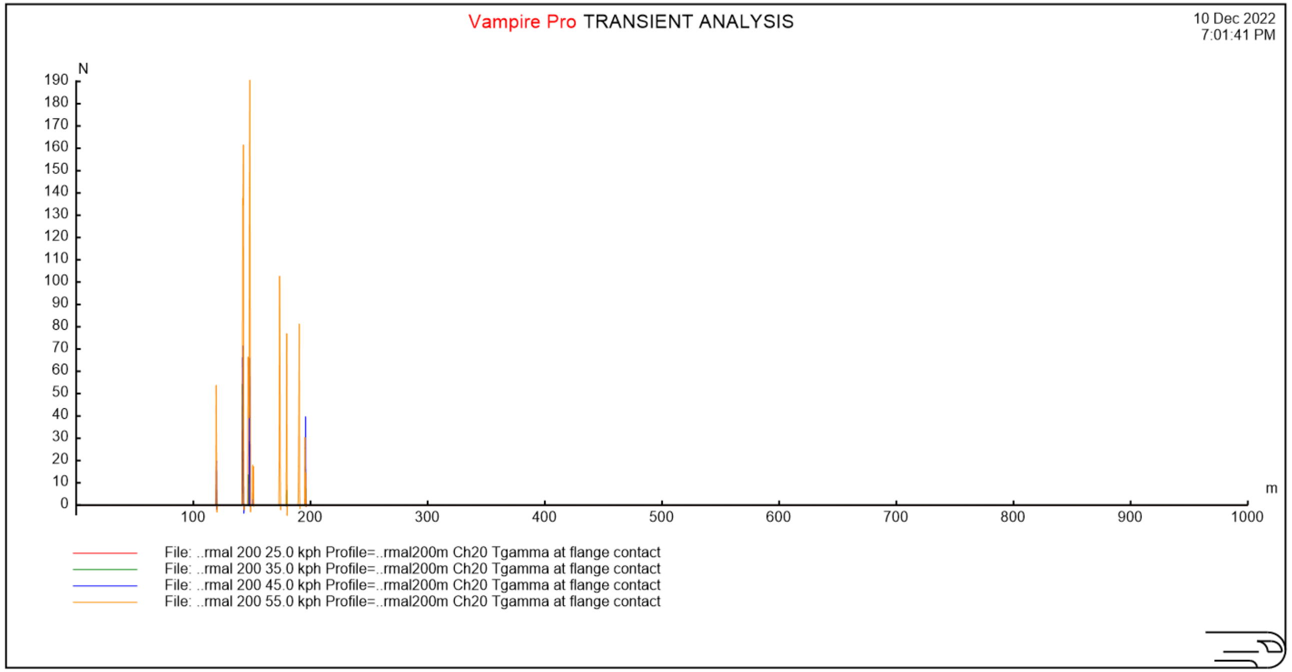
Configuration	K14	18–100
Empty	8 t	8.5 t
normal	18.6 t	22.75 t
loaded	23.6 t	27.75 t

18-100 bogie



Vampire Plot

K14 (SP) bogie

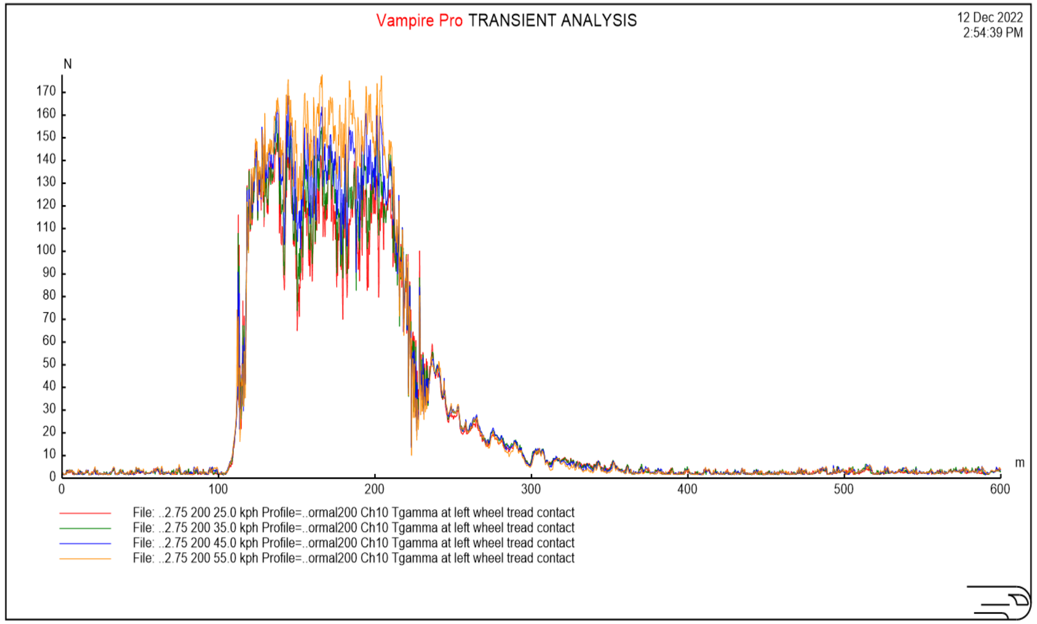


Vampire Plot

R200m

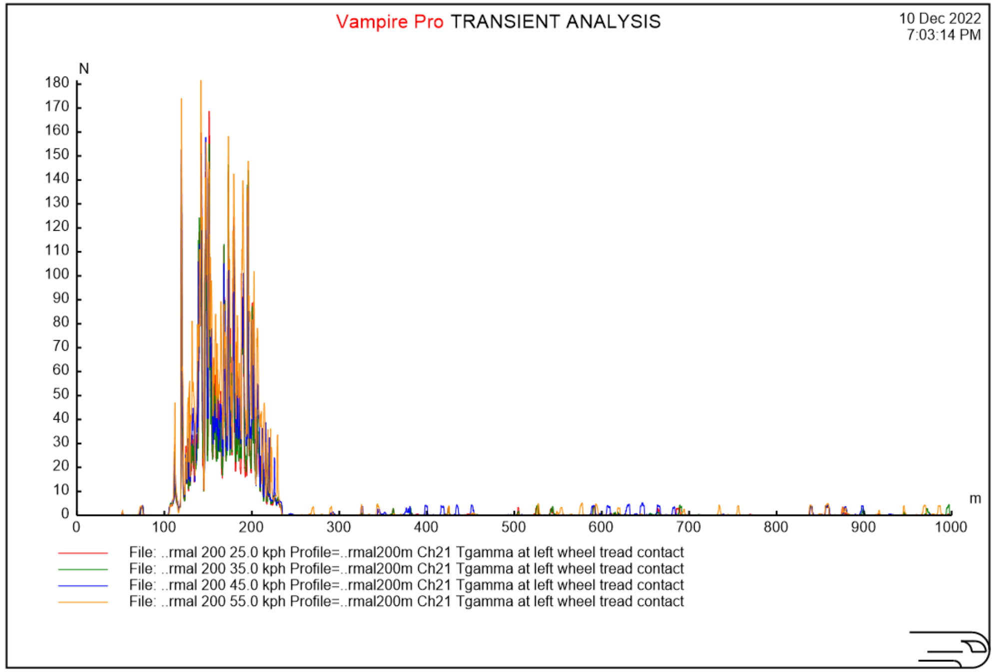
2. T-gamma value at tread contact (left)

18-100 bogie



Vampire Plot

K14 (SP) bogie

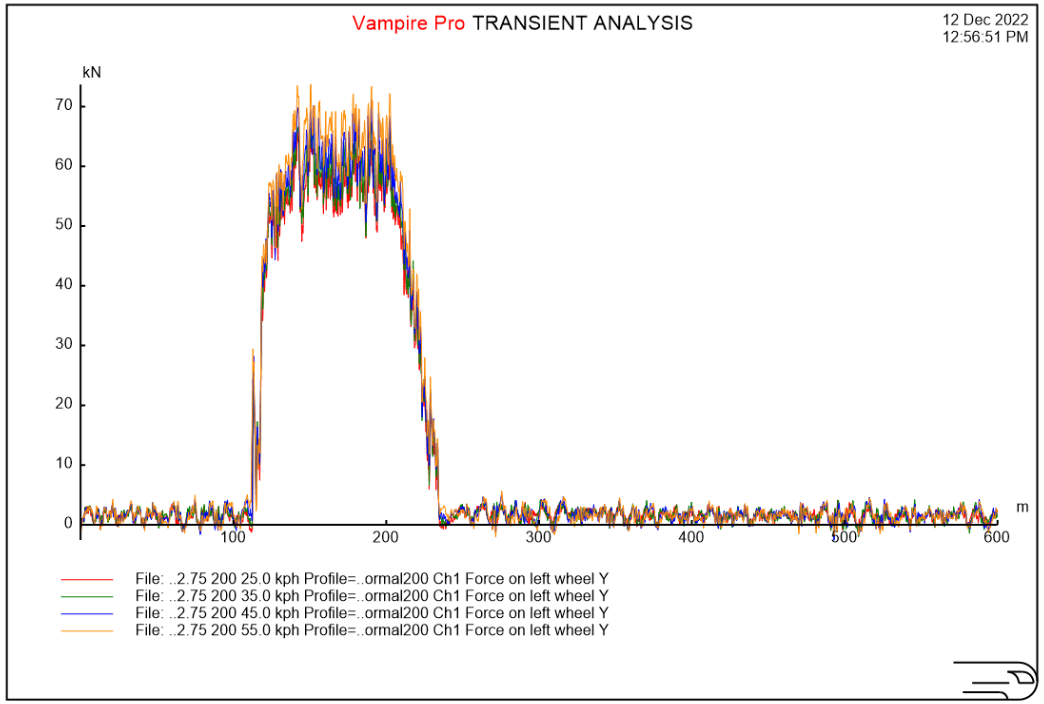


Vampire Plot

R200m

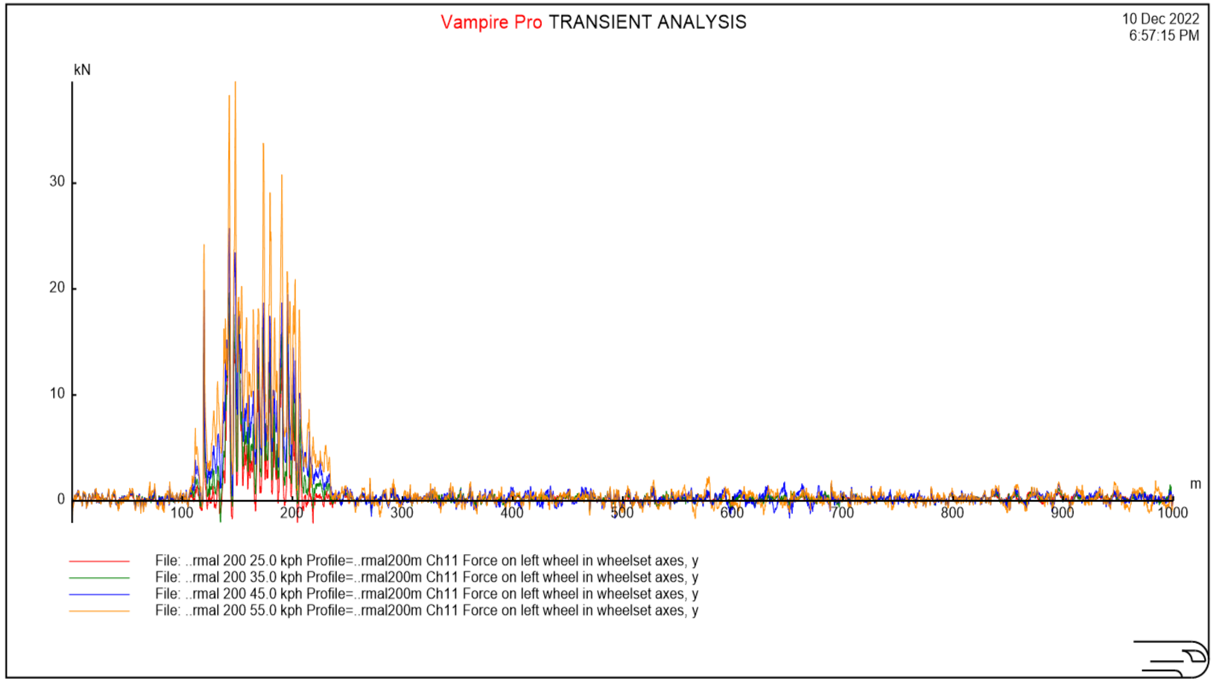
3. Lateral Force

18-100 bogie



Vampire Plot

K14 (SP) bogie

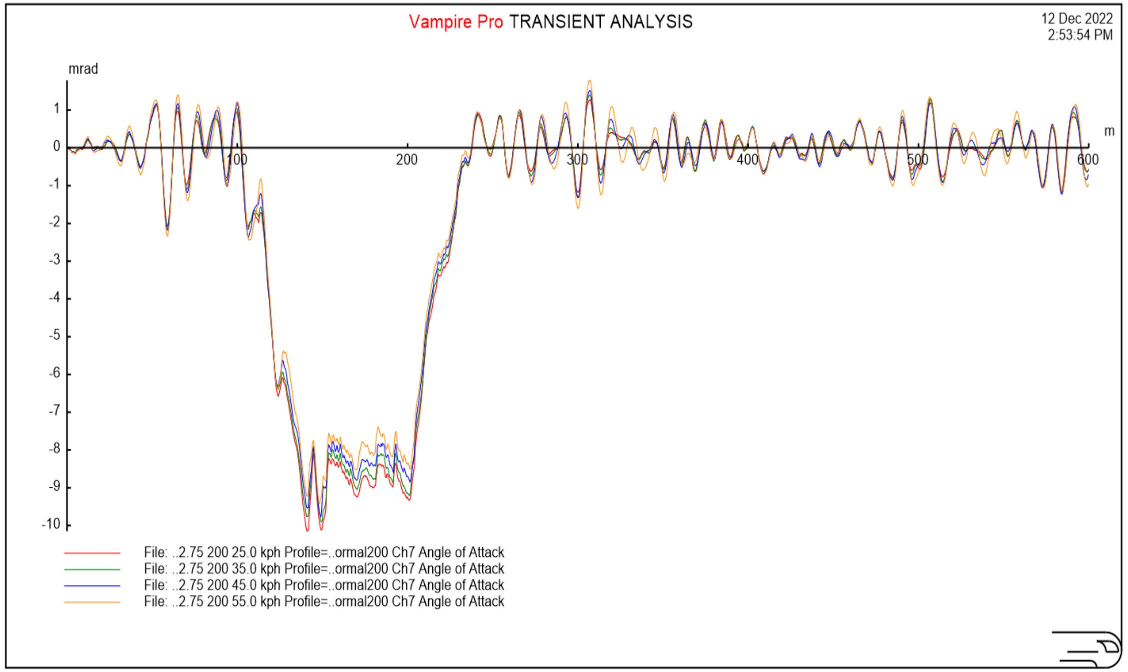


Vampire Plot

R200m

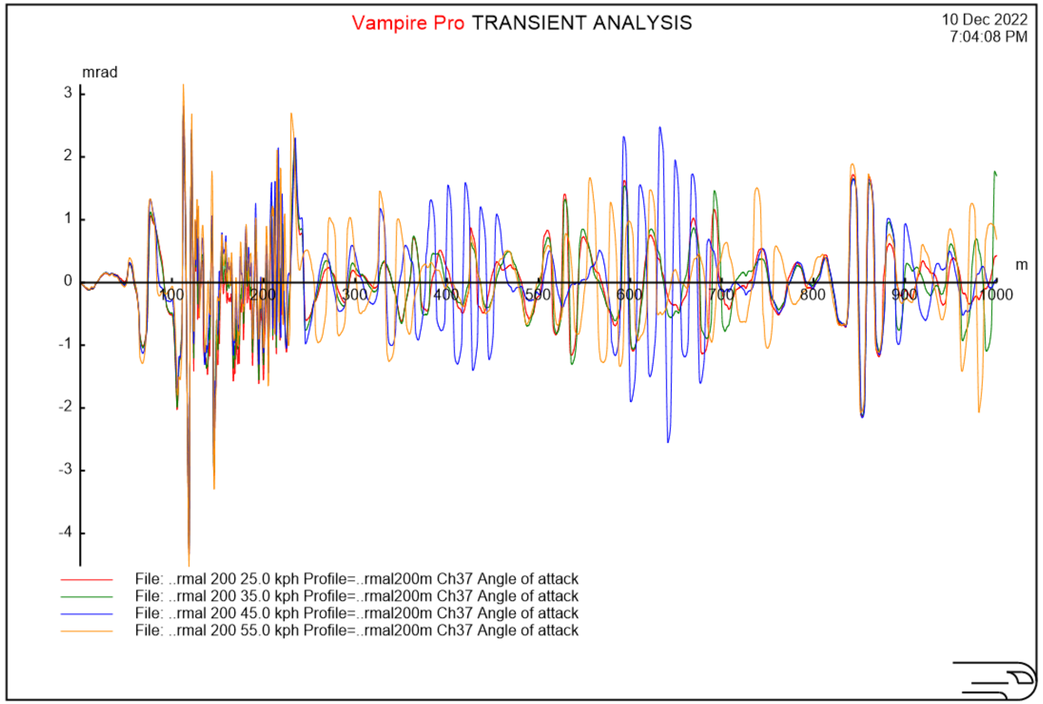
4. Angle of attack

18-100 bogie



Vampire Plot

K14 (SP) bogie

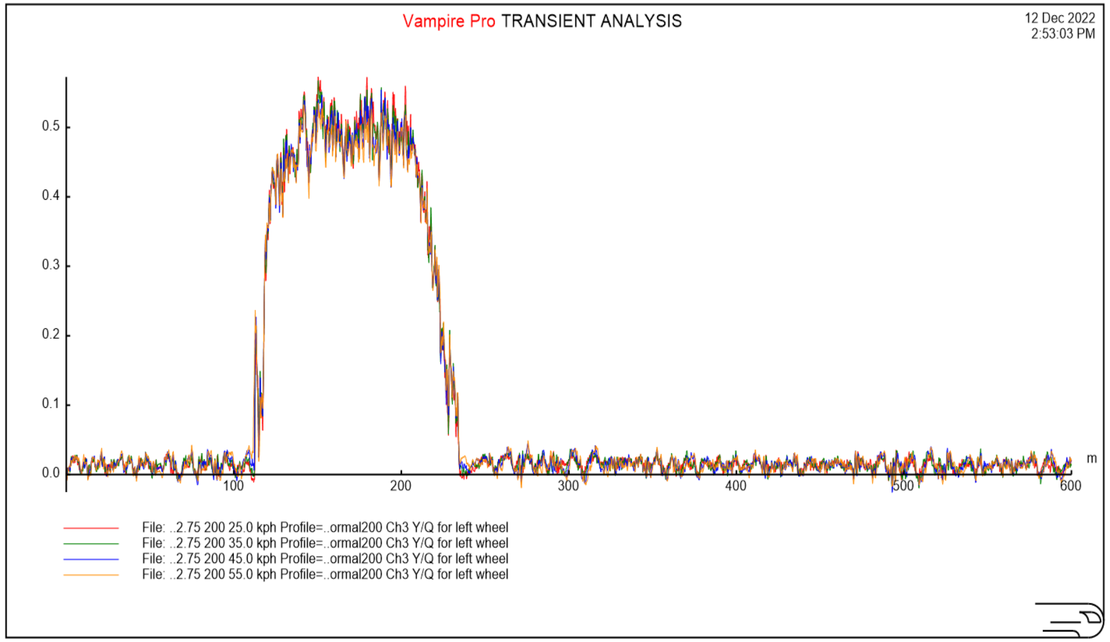


Vampire Plot

R200m

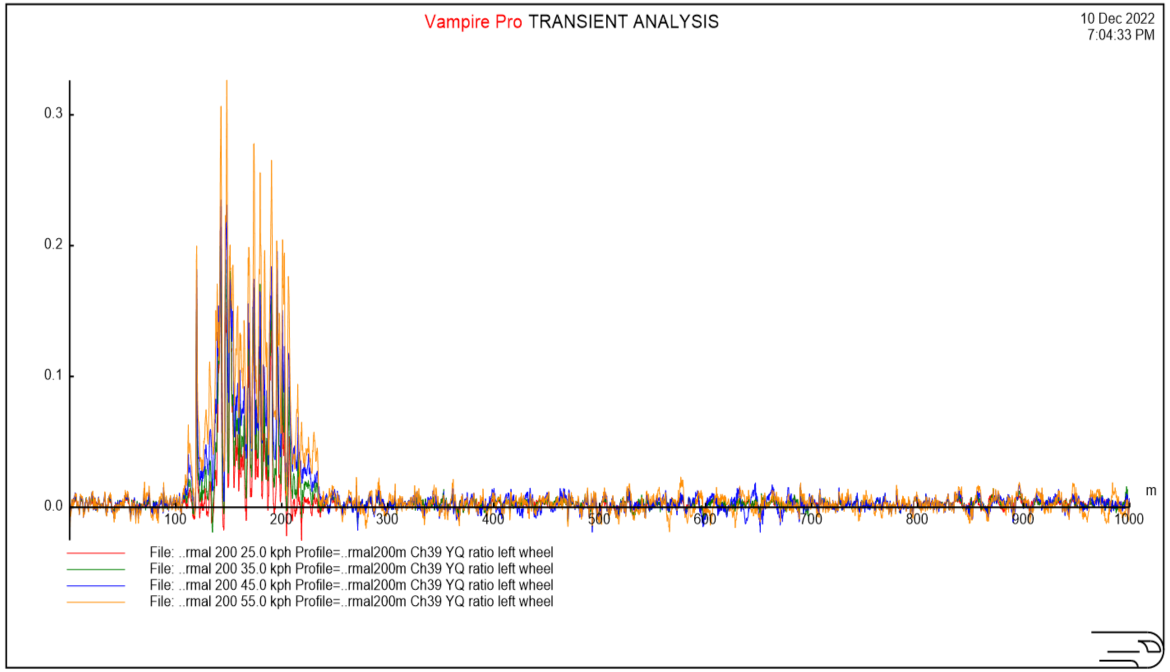
5. Y/Q derailment ratio

18-100 bogie



Vampire Plot

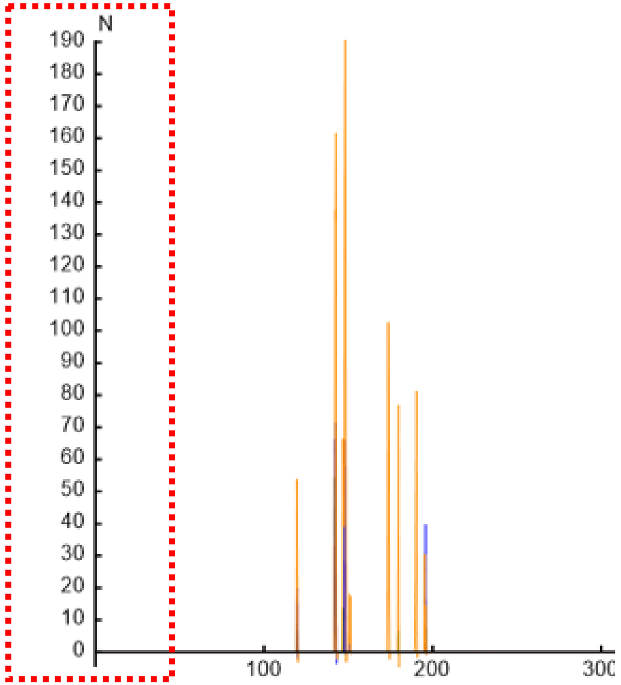
K14 (SP) bogie



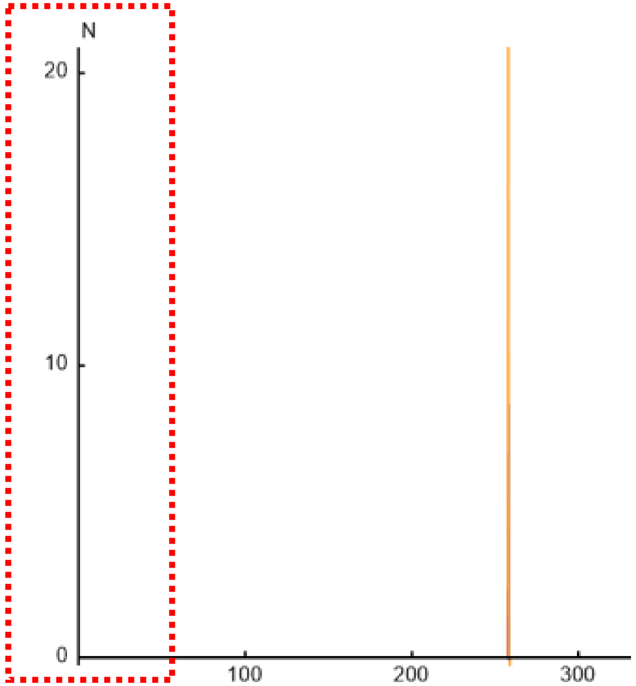
Vampire Plot

Effect of curve radii: **K14 (SP) bogie**

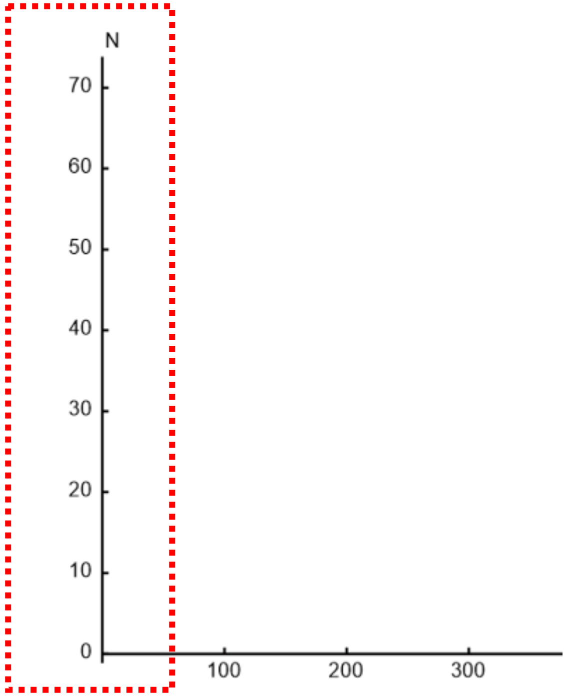
1. T-gamma flange contact



R200m



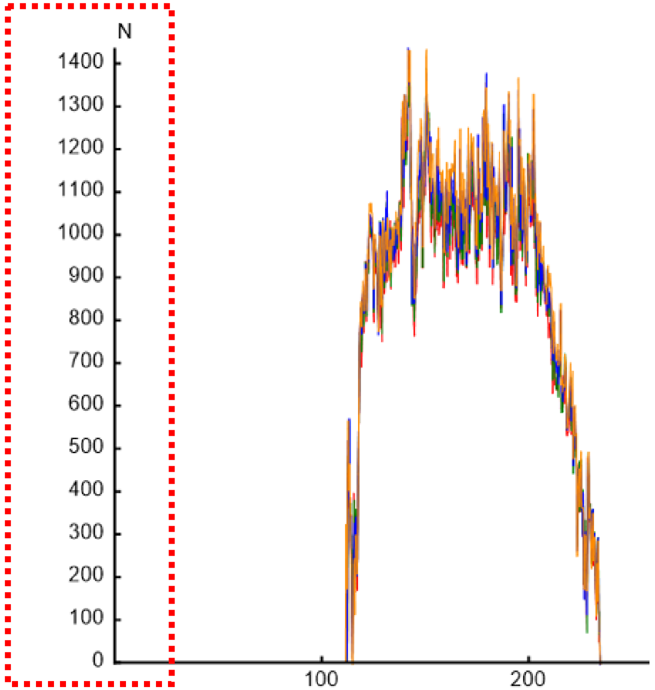
R500m



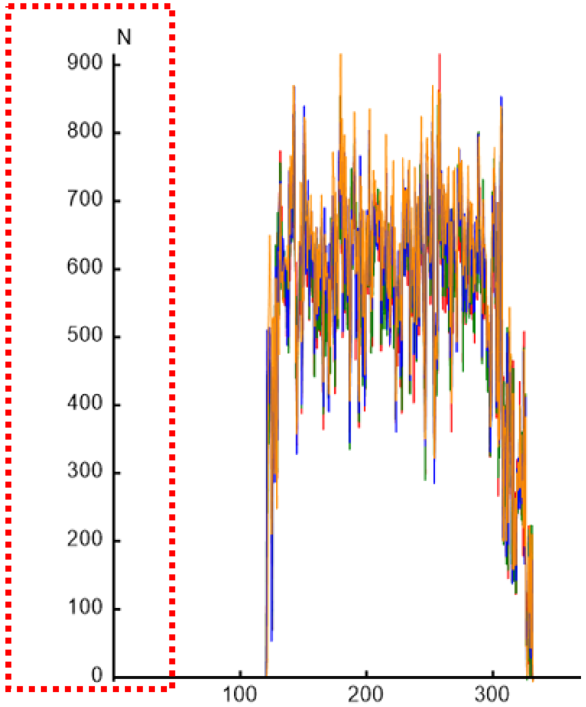
R1200m

Effect of curve radii: 18-100 bogie

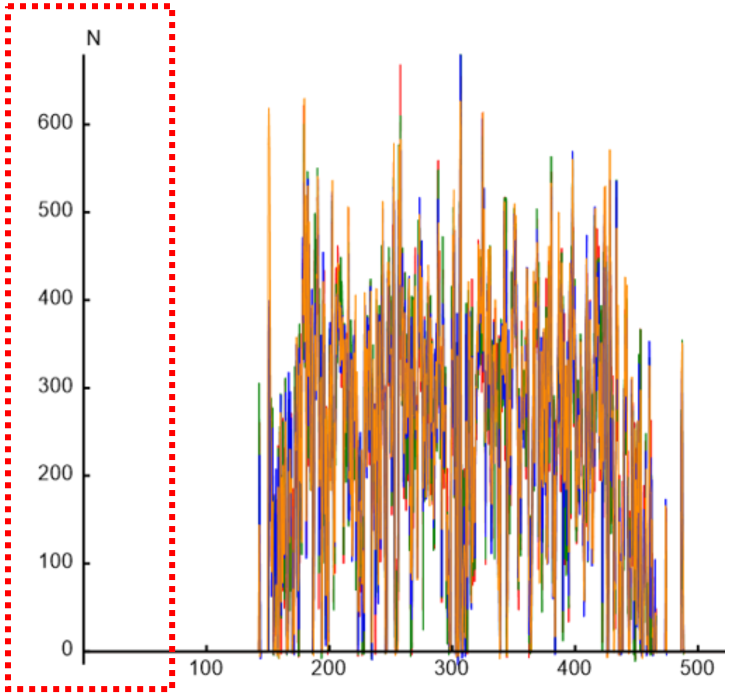
1. T-gamma flange contact



R200m



R500m



R1200m

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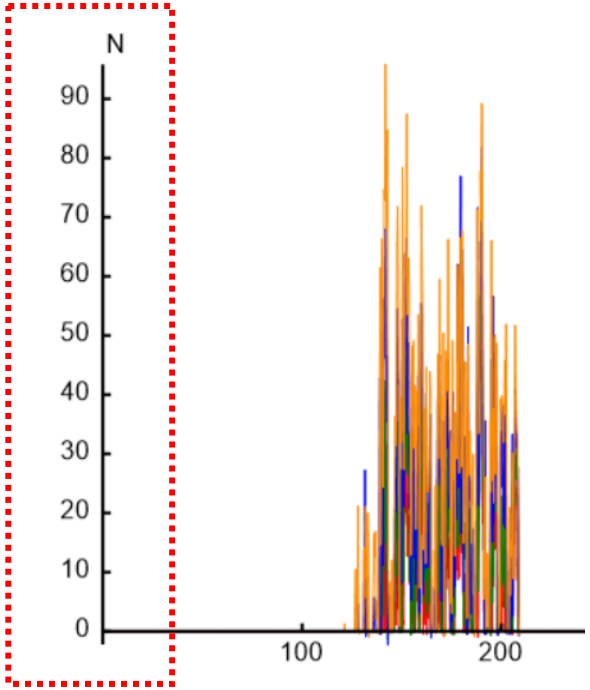
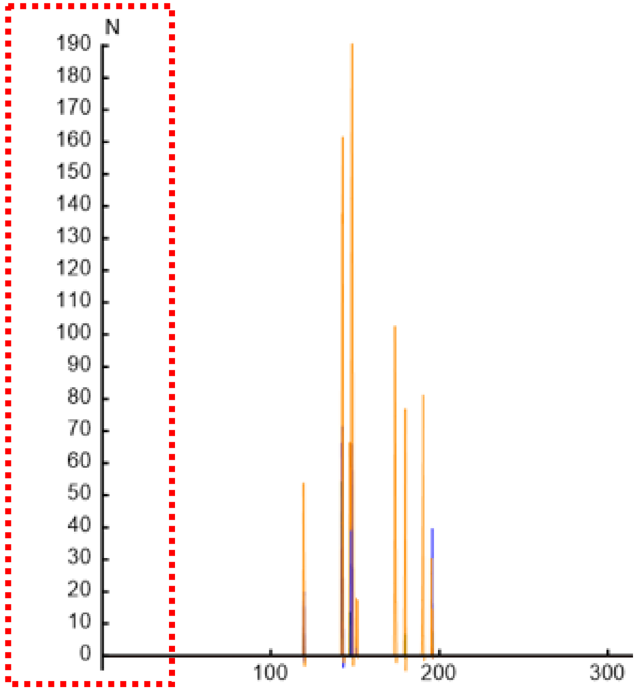
Effect of Axle Load: K14 (SP) bogie

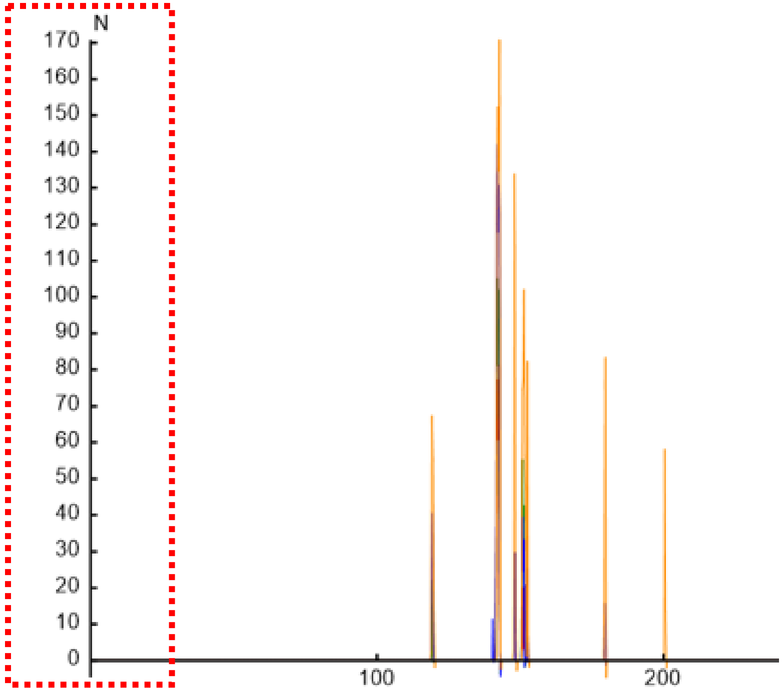
1. T-gamma flange contact



Empty



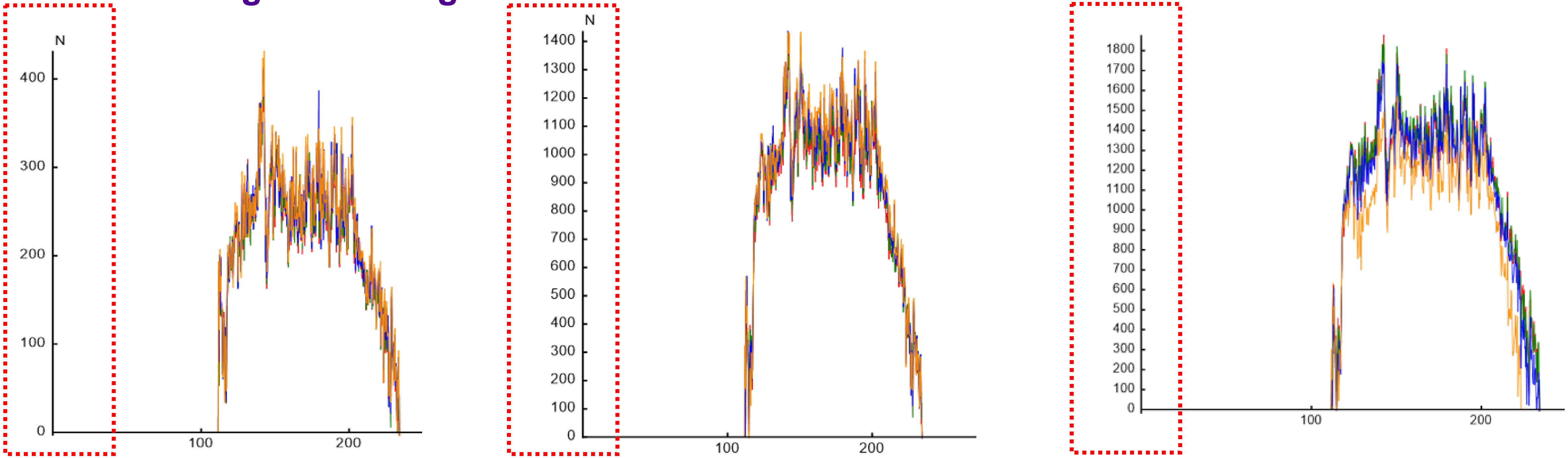
Normal



Loaded

Effect of Axle Load: 18-100 bogie

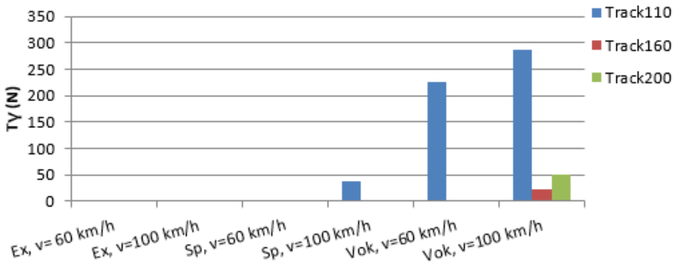
1. T-gamma flange contact



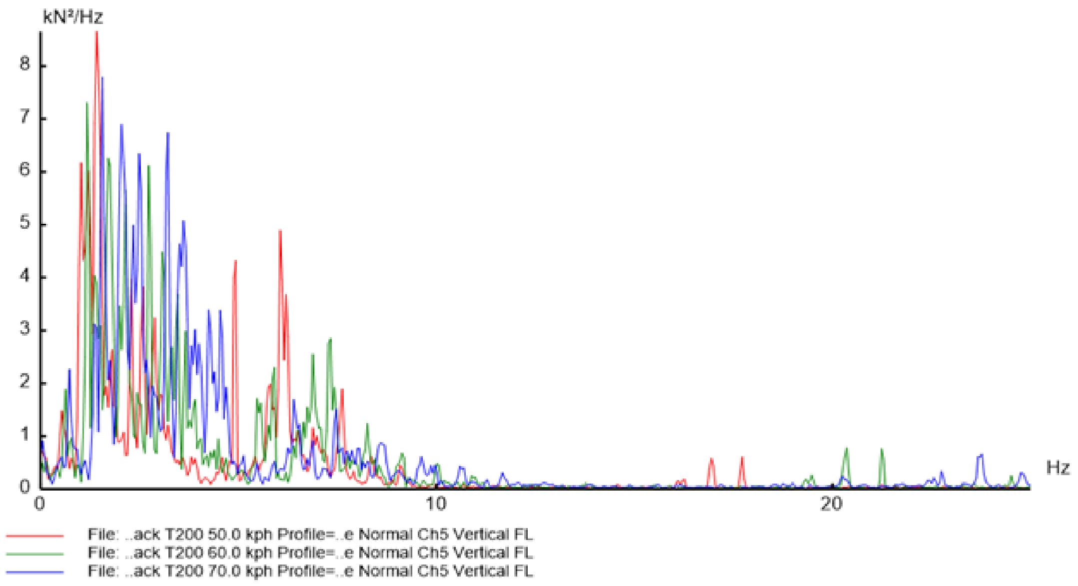
Empty **Normal** **Loaded**

Vibration?

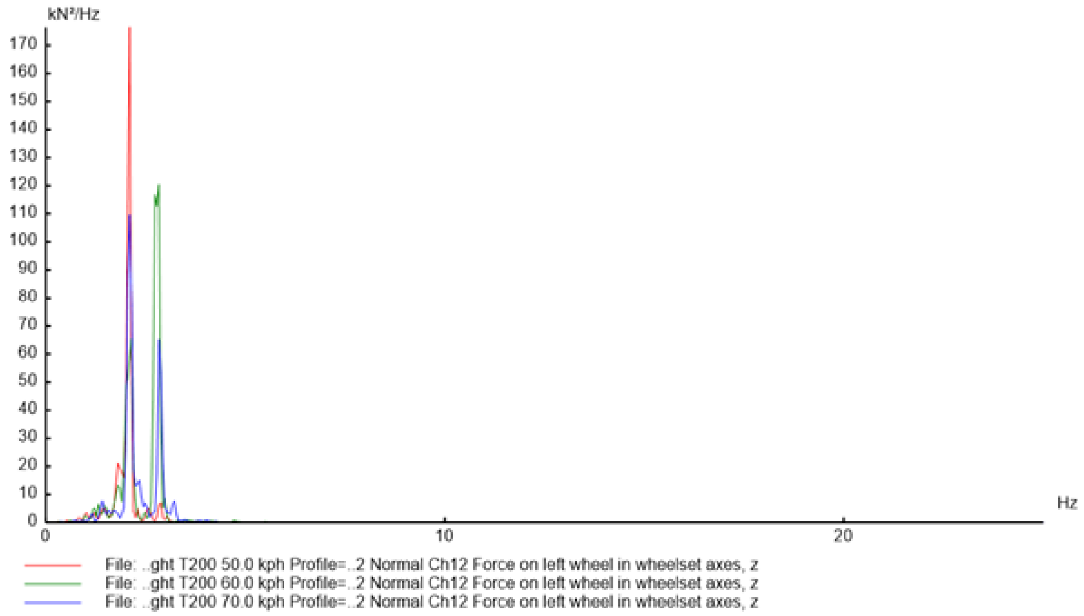
Vertical Dynamic forces (Frequency component)



18-100 bogie



K14 (SP) bogie



Inferences drawn from simulations:

- **Curve distribution:** The rail surface damage varies significantly with curvature!
- **Track quality:** Any track irregularity and rougher track quality increases wheel rail tangential forces thereby increasing the wear or RCF!
- **Axle load and the conditions of the wheels play a significant role**. Situations like suspension lock-ups simply increase the unsprung mass of the bogie and leads to high frequency wake ups.
- The **18-100 wagon** pretty much has unavoidable flange contact happening as it passes through different curve radii and produces longitudinal and lateral creep forces.
- Simulation results obtained for the 200m curve, roughly give a close approximation to the on-site measurements taken at Kouvola.
- The simulation results for a wider fleet could give an indication of how the **railway access charges could be determined in the future** according to the load on the equipment.

Thank you for attention…..

Questions???