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A Calculation Framework to Better Understand & Estimate Services Loads for Track Designers & Maintainers

RSSB projects T1073 + COF-UOH-59

Presentation to UIC TTI by

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The Queen's Anniversary Prizes
For Higher and Further Education
2019

RAIL SAFETY AND STANDARDS BOARD

Background on Track Loading Requirements

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- **Loading requirements for track system design and construction are defined in EN16432-1**
  - But there is a lack of transparency and fundamental scientific validation, particularly concerning lateral track loading

- **Guidance on lateral loads stems from limit values established to reduce the derailment risk (Nadal) and track buckling (Prud'Homme)**
  - Highly conservative or unrepresentative when considering the wide range of loading conditions and track systems
  - Leading to either over engineered or inappropriate track design suffering short life cycles

- **Could be more accurately categorised as a function of the type of application**
  - e.g. vehicle type, operational speed, track layout and track form

Background on RSSB Funded Research

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- **RSSB commissioned a detailed piece of research (T1073) to define the requirements for the design of ballasted and non-ballasted track systems**
  - Provide guidance to enable track system designers to develop designs appropriate to the loads imposed by rolling stock and an appropriate maintenance strategy

2018-2019

- **T1073 defined the requirements for vertical track loading, however, the work on lateral loading was not finalised**

2020

- **Co-funded COF-UOH-59 project was set out a for completing the lateral loading requirements**

2021

T1073 Motivations

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- **The design of track systems is continually developing, using combinations of different materials, improved manufacturing processes and construction techniques**
- Current practice for designers of new track is to use **Load Model 71 (LM71/Eurocode)** to determine loads on track support systems.
- This model was originally **developed for bridge design**, is usually applied to simply supported or continuous spans, with typical spans of 10m or less in GB. However, the design practice in GB for track renewals and upgrades is largely to use proven combinations of track components for ballasted track, based on many years of experience and practice.
- The application of structural design methods to the track system, due to the existence of a design load model, could change this practice over time, improving durability and decision making such as concerning sub-structure materials.

Figure 1: Typical ballasted track

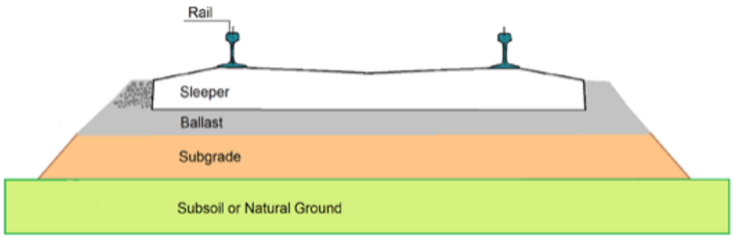
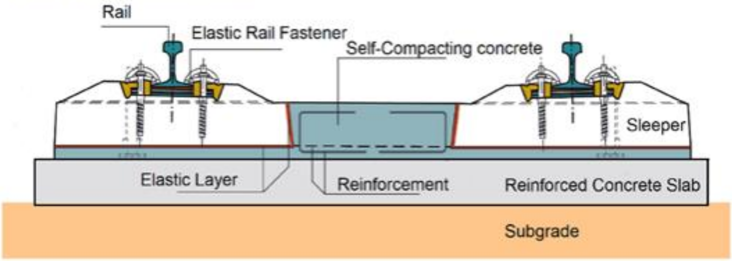


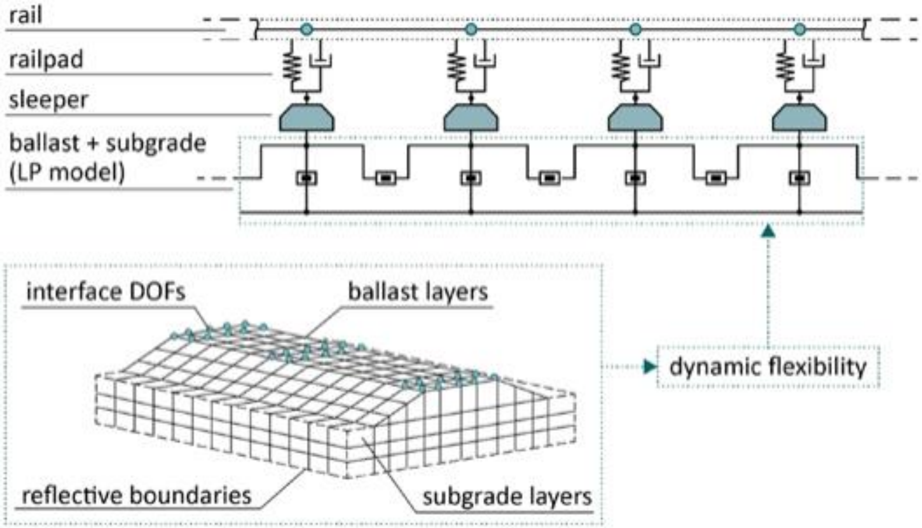
Figure 2: Typical ballastless track



Reference: https://www.rssb.co.uk/-/media/Project/RSSB/RssbWebsite/Documents/Registered/Research-Projects/2023/07/21/19/07/Research-Brief-T1073.pdf

T1073 Motivations

- The aim was to **develop a design method**, considering the loads from specific train types (*from freight to HS*), operating at relevant speed ranges, on new or upgraded track systems. The stiffness of the subgrade was also considered.
- The findings is to help track designers and clients for track design work to achieve a more efficient design, that is both <u>fit for purpose</u> and <u>cost effective</u>.



T1073 Main Findings

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- **The conclusions of the vertical load analysis are:**
- LM71 load pattern: The 250 kN point loads are likely to be the most critical load on rail tracks supported on earthworks.
- Dynamic factor functions have been developed for each train type, track type, operating speed and soil-type. This provides a more realistic representation of the vertical track load variation with speed.
- Design functions for typical types of train, and for different subgrade stiffness categories (soft, medium and stiff), have been derived.

An example of the dynamic factors obtained for New HS Trains on a ballastless track, on soft, medium and stiff clay is shown.

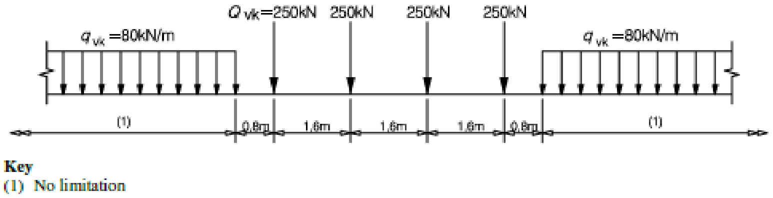
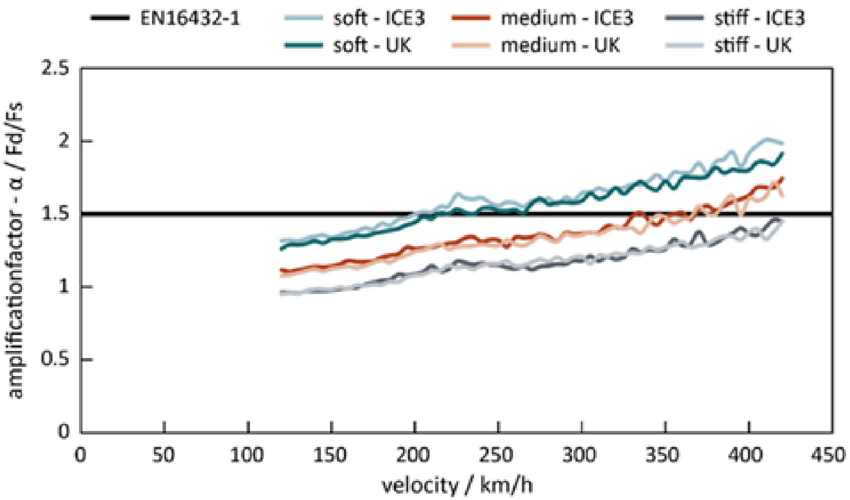


Figure 6.1 - Load Model 71 and characteristic values for vertical loads



The horizontal black line represents the constant dynamic factor of 1.5 required in EN16432-1 for all train types and track systems.

COF-UOH-59 project aims

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- **The research aimed to develop a framework which defines how lateral loads should be accounted for in track system design and its relationship to vertical loading**

- **key objectives include:**
  - Improve the definition of track loading in the current EN16432-1
  - Define a GB track load model that can then feedback into the EN standard definition
  - Support on-going/future infrastructure projects, such as HS2

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Lateral loading

COF-UOH-59

Review on lateral load limits

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Parameter	Standard	Limit values	Comments
Quasi-static lateral guiding force, Y_{qst}	UIC518 EN14363 Lichtberger	60 kN (R = 350 m) 60 kN 5 – 20 kN (high-speed) 10 – 50 kN (mixed traffic)	$Y_{qst,lim}$ = (30+10500/Rm), up to $Y_{qst,lim}$ = 112.5 kN - Range of loads to be considered for new track designs
Maximum lateral force, Y_{max}	GC/RT5021 GM/RT2141 EN14363 Lichtberger	100 kN 71 kN 80 – 110 kN 65 kN (high-speed) 91 kN (mixed traffic)	- Distributed over 2 m. - Equivalent theoretical P2 force (< 100 Hz), generated by Class 86/2 loco in a curve over prescribed lateral ramp on outer rail. - No limit value is provided, but Annex J provides guidance. - Defines range of loads to be considered for new track designs
Track lateral shifting force, $\sum Y_{max}$	GM/RT2141 EN14363	variable (e.g. 81 kN for class 86/2) variable	K_1 (10+P_0/3), with P_0 = wheelset force, K_1 = 1 (loco/pass) or 0.85 (freight)
Additional track loading parameters, without limit values			
Quasi-static resultant rail force, B_{qst}	EN14363	Y_{qst} + 0.83 * Q_{qst}	Quasi-static rail load parameter
Maximum resultant rail force, B_{max}	EN14363	(|Y| + 0.91 * Q_{max})	Maximum rail load parameter

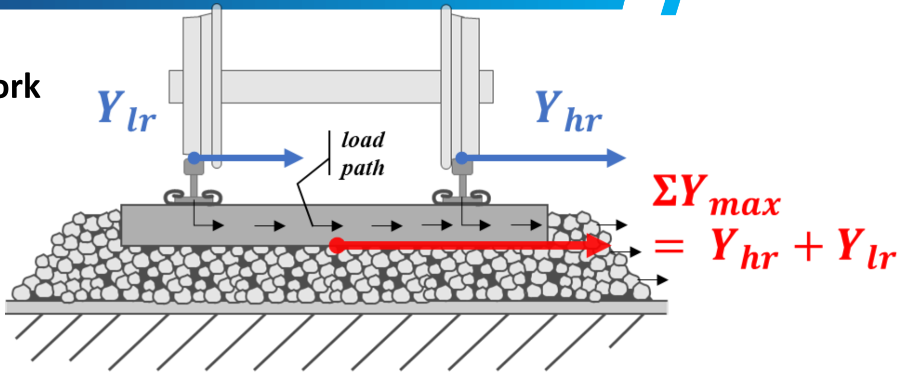
Relevant lateral forces

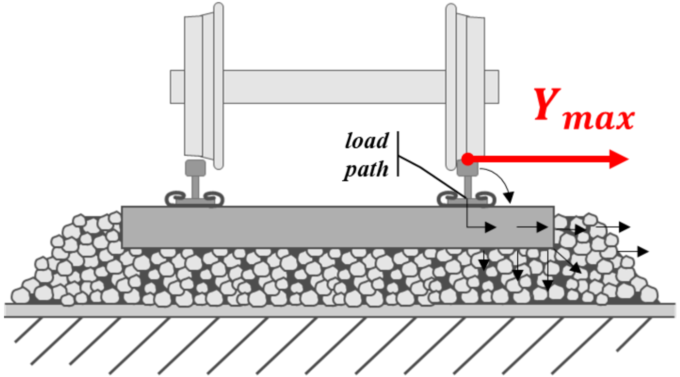
Relevant lateral forces considered in the Framework

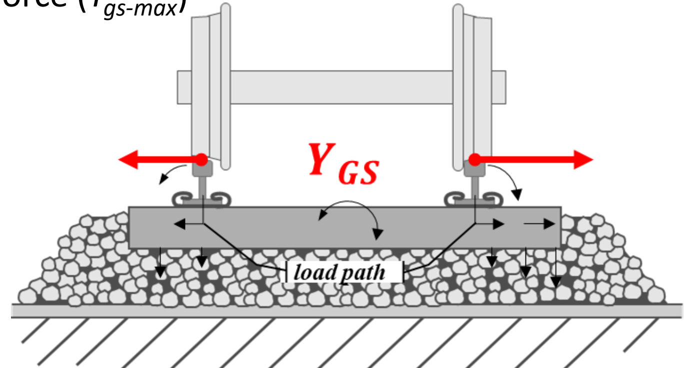
1. Track lateral shifting force ($\sum Y_{max}$)

2. Maximum Lateral Force (Y_{max})

3. Gauge spreading force ($Y_{gs\text{-}max}$)



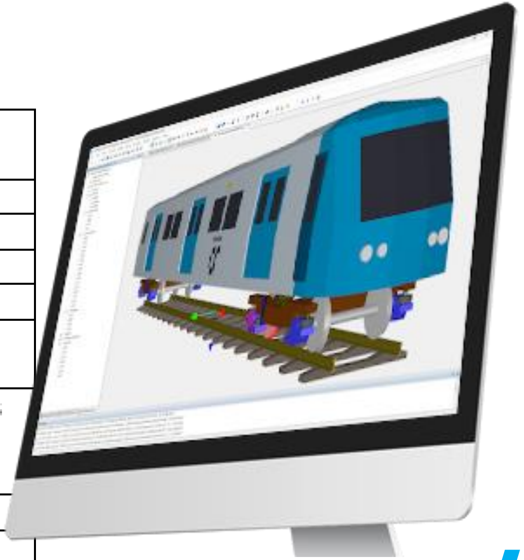




Derivation of track forces database using MBS outputs

Table 2: Summary table of input parameters used to derive lateral load limit values

Vehicle Type - Input parameters	Passenger		Freight		Loco	High Speed	Metro/ Light Rail
	2-axles	4-axles	2-axles	4-axles			
Main parameter of influence: key driver of limit values:							
Curve radius (m)	80 – 10,000						
Medium influence: entire range accounted in deriving limit values:							
Max. speed (mph)	75	100	60	75	80 – 125	225	50 – 62
Cant deficiency (mm)	0 – 150		0 – 110			0 –150	0 – 110
Track Quality	NR - bands 5, 6 and 10					HS1 VTT	LUL – bands 1 to 3 NR - Tram-Train route
Low or no influence: single representative value used to derive limit values:							
Rail type	56E1, 60E2					60E1	56E1, 55G1
Wheel type	P8		P5	P10	P8	S1002	LT5, Mod-DIN
Coefficient of friction	0.45 (worst case)						



MBS simulations using Vampire® software

Influence parameters vs Assessment criteria

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Parameter	Assessment Criteria			
	$\sum Y_{max}$	Y_{max}	Y_{gs}	Y_{bt}
Vertical static/dynamic load (Q)	High	High	High	Medium
Curvature	High	High	High	Medium
Cant deficiency	High	High	High	Medium
Track quality	Medium	Medium	Low	Medium
Vehicle instability	Medium	Medium	Low	Low
Short wavelength irregularities	Medium	High	Low	Low
Rate of change of cant	Low	Low	Low	Low
Wheel-rail profile	Low	Low	Low	Low

Comparison to limits values: vehicle type

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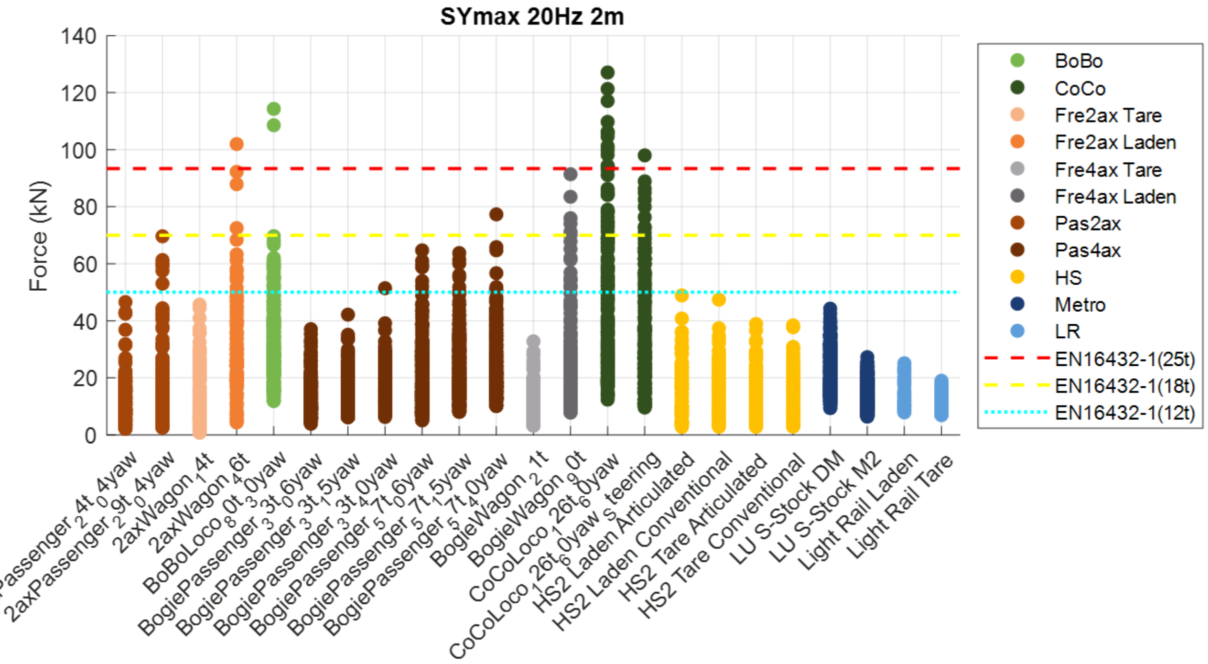
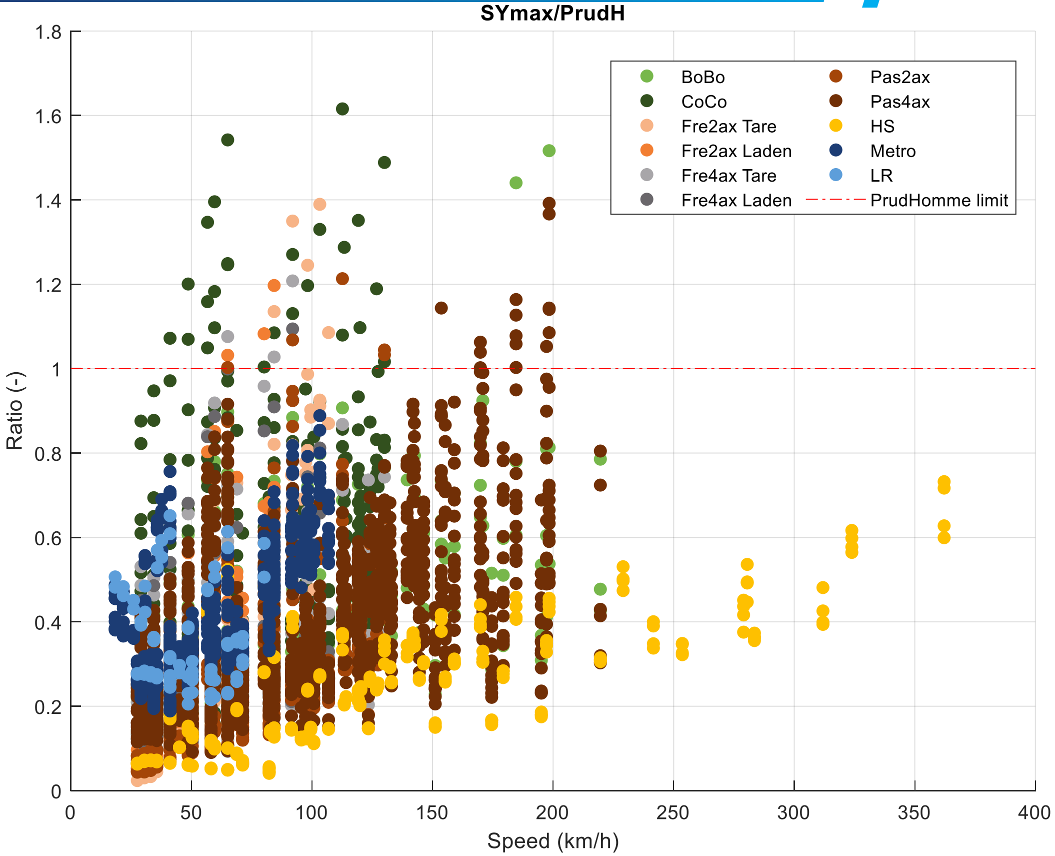
- **General over or under-estimation vs existing limit values are observed.**
- **Vehicle type and axle load obviously is a primary factor for track loading**



Comparison to limits values: vehicle speed

- Ratio (ΣY_{max} / Prud'H limit) vs **speed**
- Large exceedance for certain vehicle types at low/medium speeds
- But also not as linearly dependent on speed as for vertical loads
- Other factors have a greater influence



Comparison to limits values: curve radii

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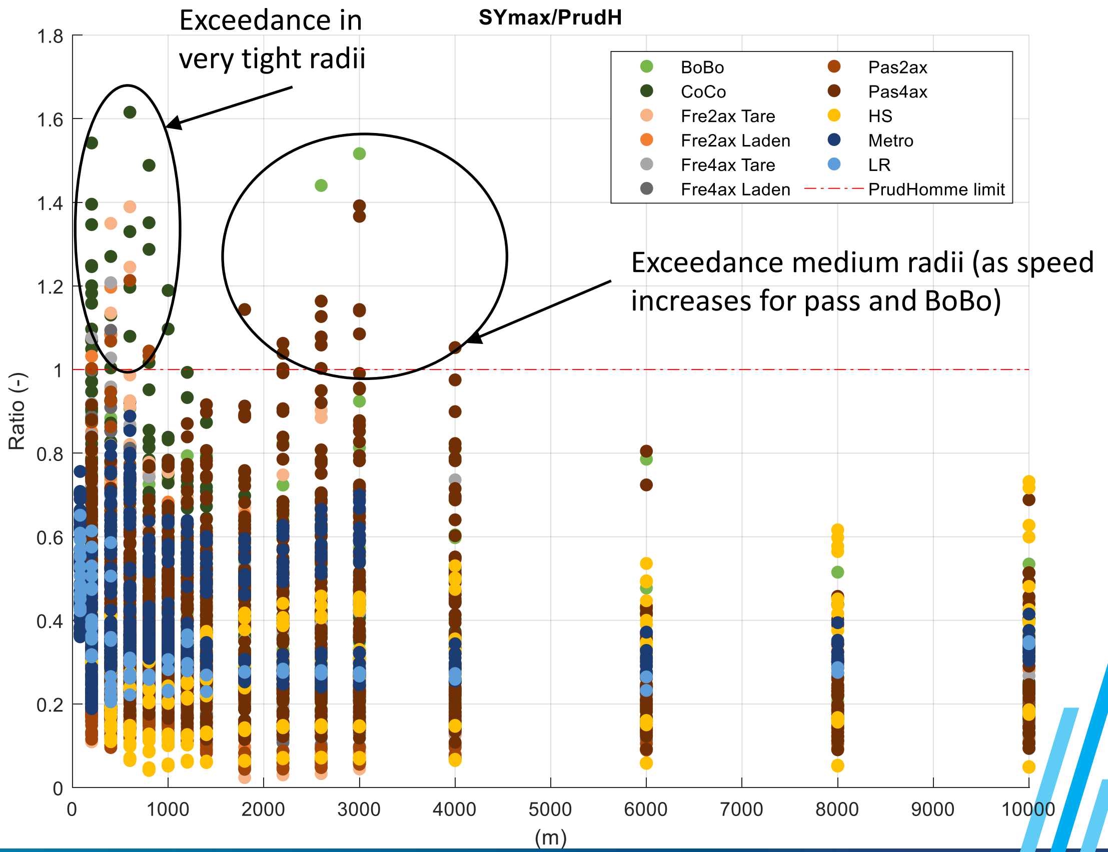
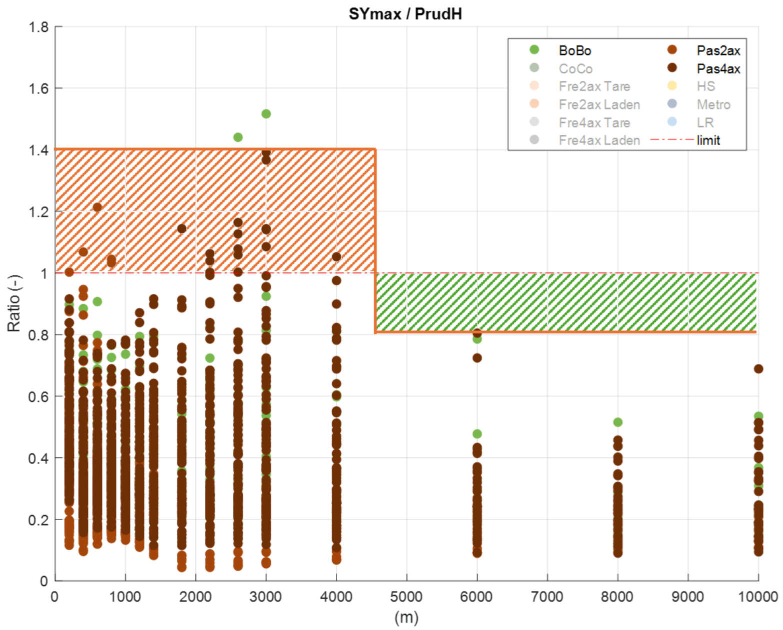
- Ratio (ΣY_{max} / Prud'H limit) vs radii
- Large exceedance in tights radii
- Also exceedance in medium large radii for passenger traffic running at high cant deficiency
- Generally low values in large radii to straight track.



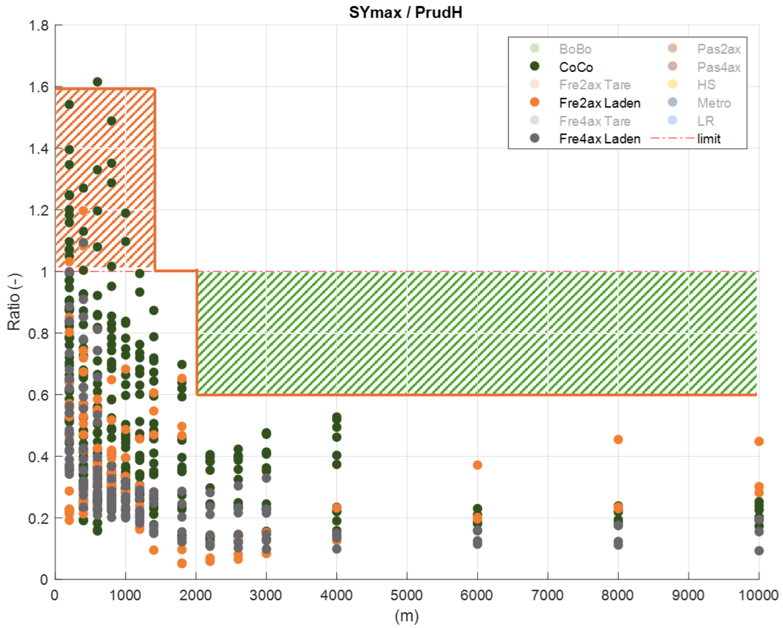
Comparison to limits values: curve radii

- **Areas of over design specification and areas of under design specifications**

Passenger



Freight / Loco



Comparison to limits values: curve radii

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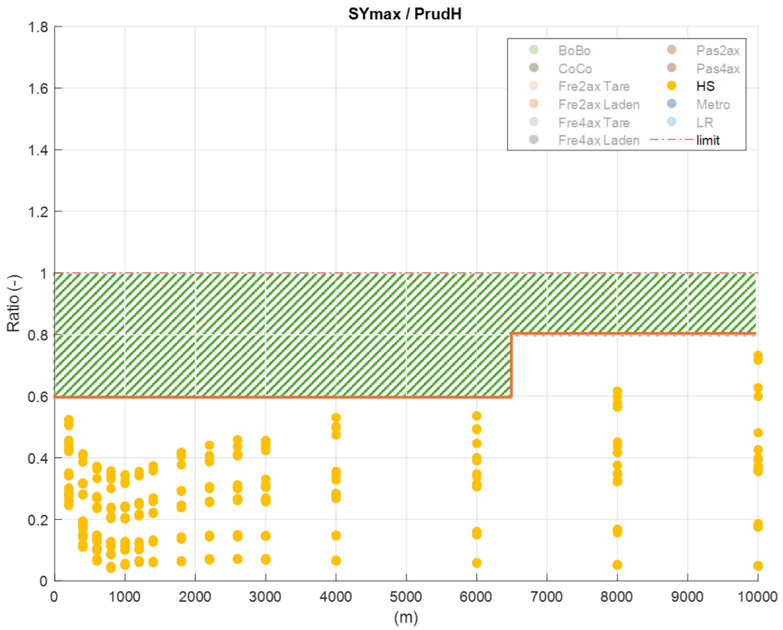
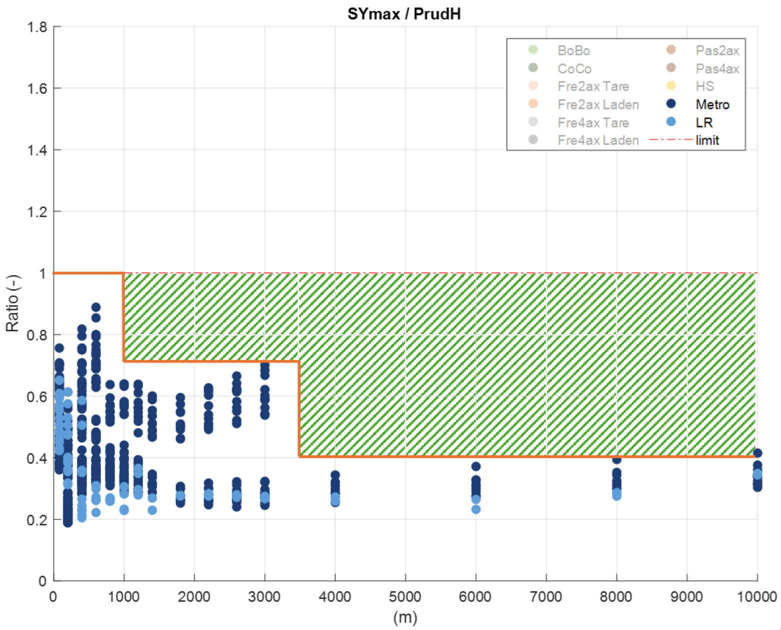
- **Mostly over design specification**

HS



tram / light rail



Comparison to limits values: cant deficiency

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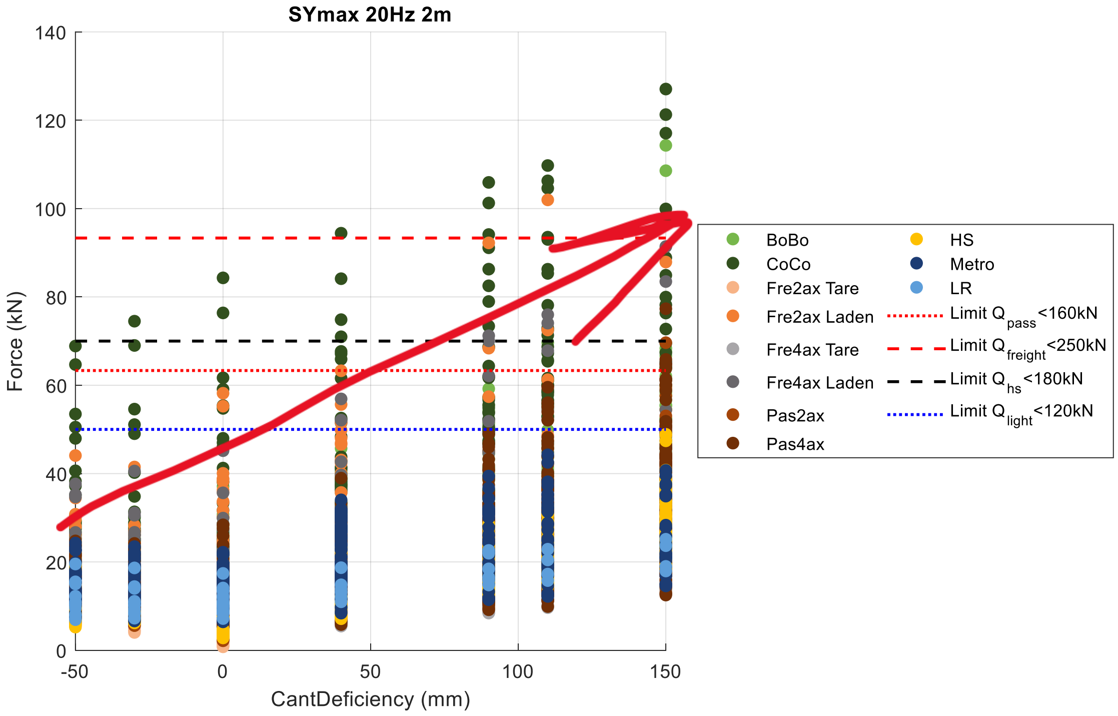
- **Significant increase of $\sum Y_{max}$ with increasing *cd* for all vehicle types**



Proposal for a loading framework

Proposed framework

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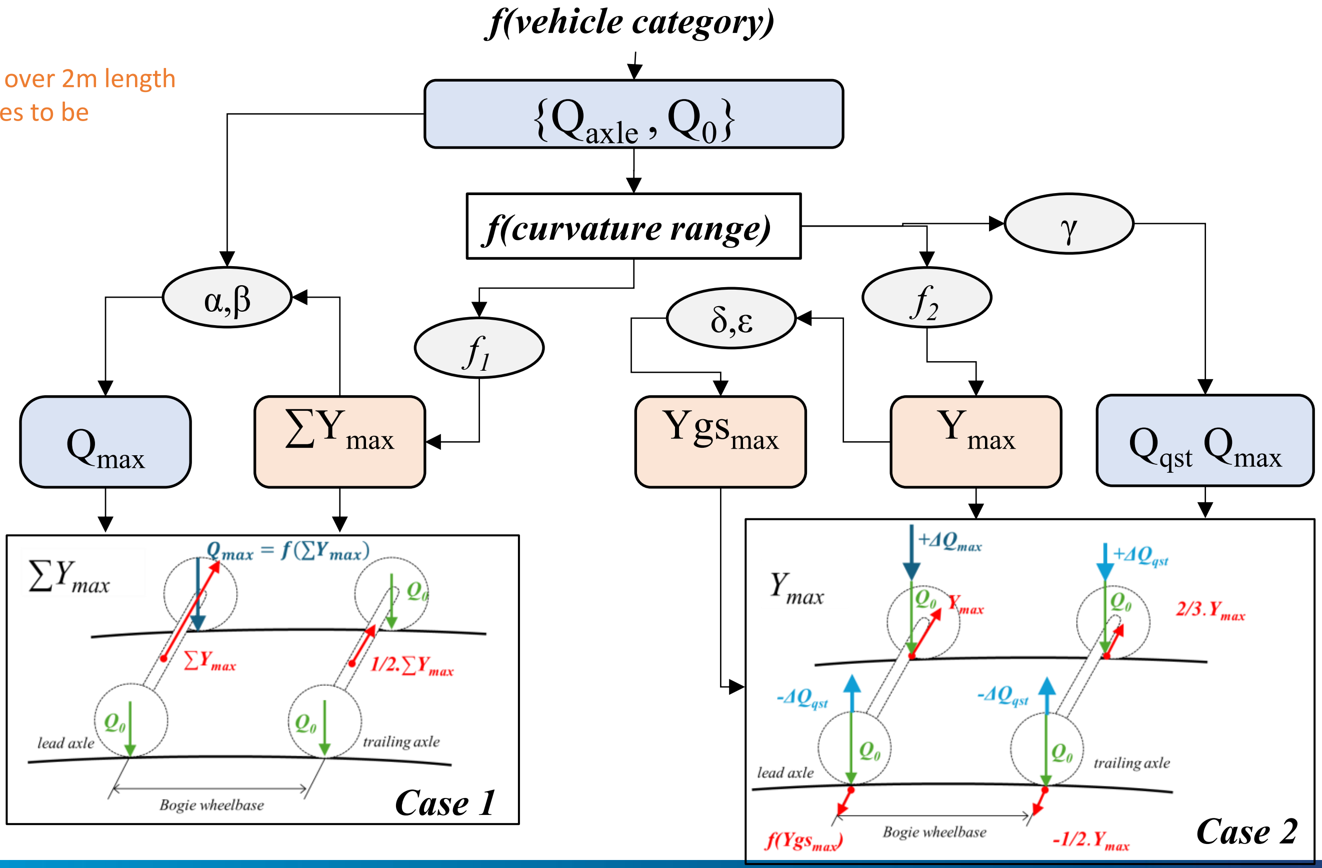
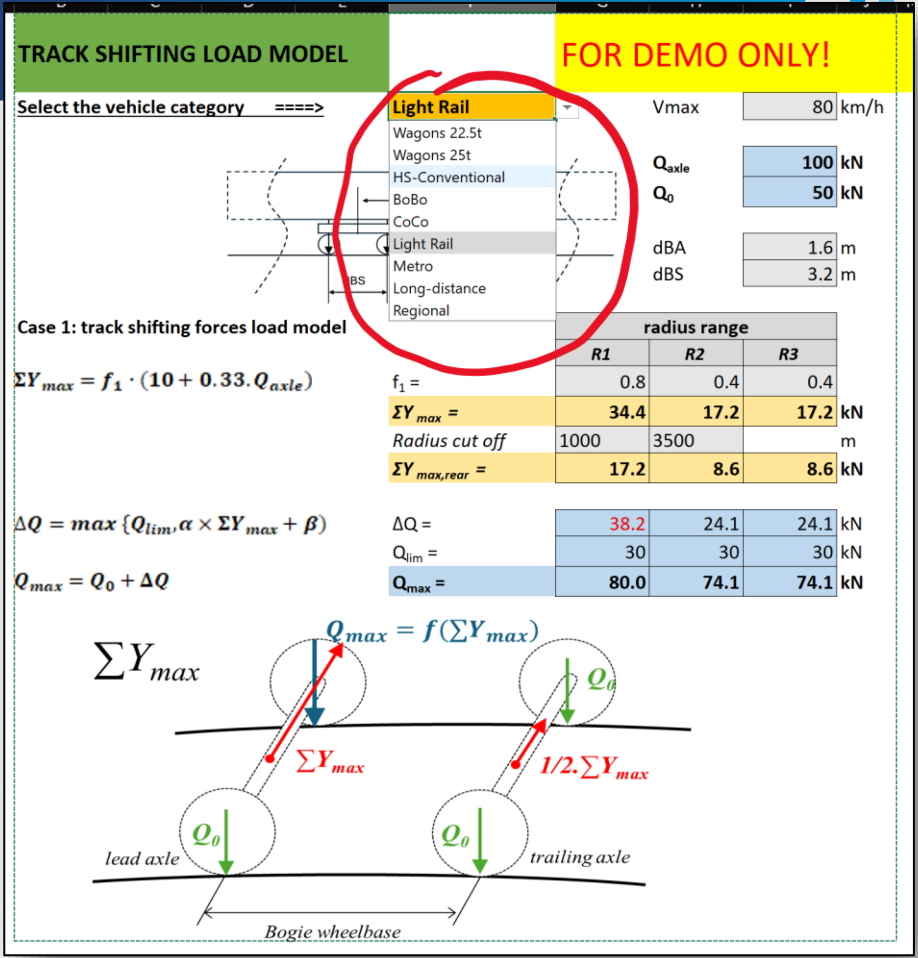
N.B. 1) Load to be applied over 2m length
2) 2 consecutive bogies to be considered



Proposed framework

- **Demo calculation spreadsheet (link)**



TRACK SHIFTING LOAD MODEL | FOR DEMO ONLY!

Select the vehicle category ====> **Light Rail**

Wagons 22.5t
Wagons 25t
HS-Conventional
BoBo
CoCo
Light Rail
Metro
Long-distance
Regional

Vmax	80	km/h
Q_{axle}	100	kN
Q_0	50	kN
dBA	1.6	m
dBS	3.2	m

Case 1: track shifting forces load model

$$\Sigma Y_{max} = f_1 \cdot (10 + 0.33 . Q_{axle})$$

$$\Delta Q = max\,\{Q_{lim}, \alpha \times \Sigma Y_{max} + \beta\}$$

$$Q_{max} = Q_0 + \Delta Q$$

	radius range			
	R1	R2	R3	
f_1 =	0.8	0.4	0.4	
ΣY_{max} =	34.4	17.2	17.2	kN
Radius cut off	1000	3500		m
$\Sigma Y_{max,rear}$ =	17.2	8.6	8.6	kN
ΔQ =	38.2	24.1	24.1	kN
Q_{lim} =	30	30	30	kN
Q_{max} =	80.0	74.1	74.1	kN

Conclusions

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- Current **Vertical loads factors** are over simplified and should account for vehicle **speed** and track **stiffness**
- **Lateral loads** are more complicated and should account for additional factors such as vehicle type, track layout, track type and operational cant deficiency. Vertical and lateral loads are also **interlinked**.
- For track design purposes the major type of lateral loading criteria are track shifting $\boldsymbol{\sum Y_{max}}$, rail loading $\boldsymbol{Y_{max}}$ and gauge spreading force $\boldsymbol{Y_{GS,max}}$
- **Current limits** used in relevant standards (e.g Prud'Homme) can grossly **overestimate** the expected forces for most vehicles, except for heavy freight and locomotive, and **under predict** in tight radii for the same vehicle category. This justifies the need for **new and variable limit values**.
- A simple calculation **framework** is proposed for track design purposes considering combinations of Y and Q load cases and proposes a systematic way of deriving their limit values.
- This will also help **better track maintenance** for IMs supporting better maintenance **planning models** to be developed

Further work and next stage

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Draft framework presentation to industry stakeholders and opened for consultation:

- Via the GB CEN16432 mirror working group BSI RAE/2/-/8.

Areas that have to be considered for further work are:

- vehicle **instability** and generated additional lateral loads (quantification of additional factor and estimate of likely risk as a function of operational type)
- investigate **track load distribution** based on a wider variety of track design and formation to understand links between WRI loads and strains in the various track components/levels.
- investigation of high loads generated from **CoCo locomotives**, noting that these vehicles are infrequent
- consideration for **higher frequency dynamic loads** – here all low pass filtered <20Hz with 2m sliding mean. There are increased dynamic factors for short wavelength track input (e.g. joint, welds, S&C, corrugations) and wheel OoR/flats.
- Potential **laboratory testing** to verify track lateral resistance to established limits

References

- B. Lichtberger, “Track compendium,” Eurailpress Tetzlaff-Hestra GmbH Co. KG, Hambg., vol. 634, 2005.
- EN14363:2016+A1:2018, “Railway applications - Testing and Simulation for the acceptance of running characteristics of railway vehicles - Running Behaviour and stationary tests”
- EN16432-1:2017, “Railway applications — Ballastless track systems – Part 1: General requirements”.
- GMRT2141 Issue 4.1, “Permissible Track Forces and Resistance to Derailment and Roll-Over of Railway Vehicles”.
- GCRT5021 Issue 6, “Track System Requirements”, issued 2/12/2023.
- RSSB Project T1073, “Loading requirements for track systems (T1073) - Analysis and guidance on vertical track loading requirements for track designers”, 2020.
- RSSB project COF-UOH-59, “Loading requirement for tracks systems - lateral loading (COF-UOH-59), 2023.

Thank you.

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