MTEC a member of NSTDA

Computational simulation for understanding rail dynamics safety

Presented by

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on November 22nd, 2023

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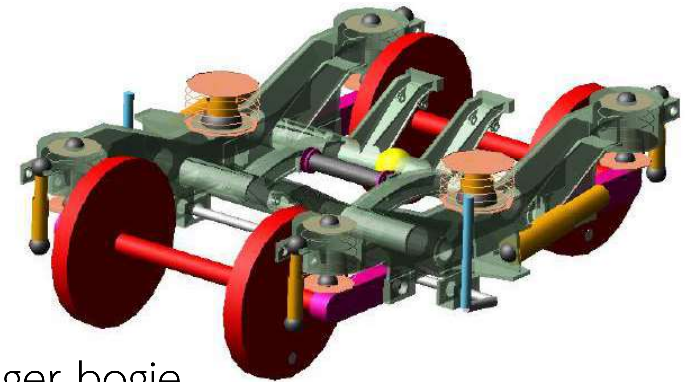
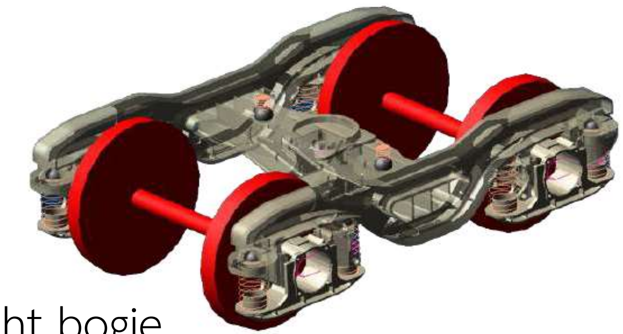
Major types of trains in consideration

Passenger wagon



Passenger bogie

Freight car



Freight bogie

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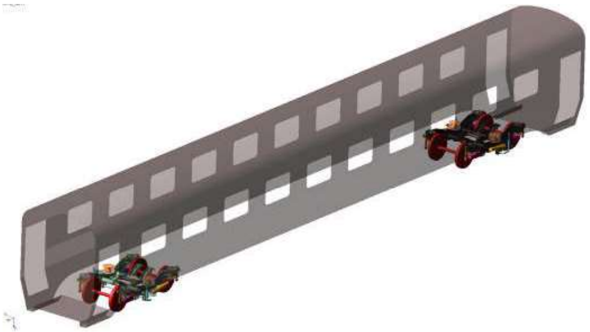
Vehicle acceptance analysis

Running safety, Track loading, Ride characteristics	
	
EN14363:2005 - Railway applications - Testing for the acceptance of running characteristics of railway vehicles - Testing of running behaviour and stationary tests.	Association of American Railroads – Safety and Operations. MSCP-C-II: Manual of Standards and Recommended Practices – Section C – Part II. Design, Fabrication and Construction of Freight Cars. Chapter 11 – Service worthiness tests and analyses for new freight cars. Issue of 2007

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Main objectives – Increase load capacity with safety issues intact

Wheel/Rail contact pairs

- Wheel/Rail profiles
- Remaining life and damage mechanism – wear and rolling contact fatigue
- Wheel and rail materials

Vehicle design

- Car body strength and natural frequency
- Bogie frame strength and natural frequency
- Primary and Secondary suspension configuration and parameters

Track design

- Gauge system
- Track quality
- Foundation construction

Loading – Axle load

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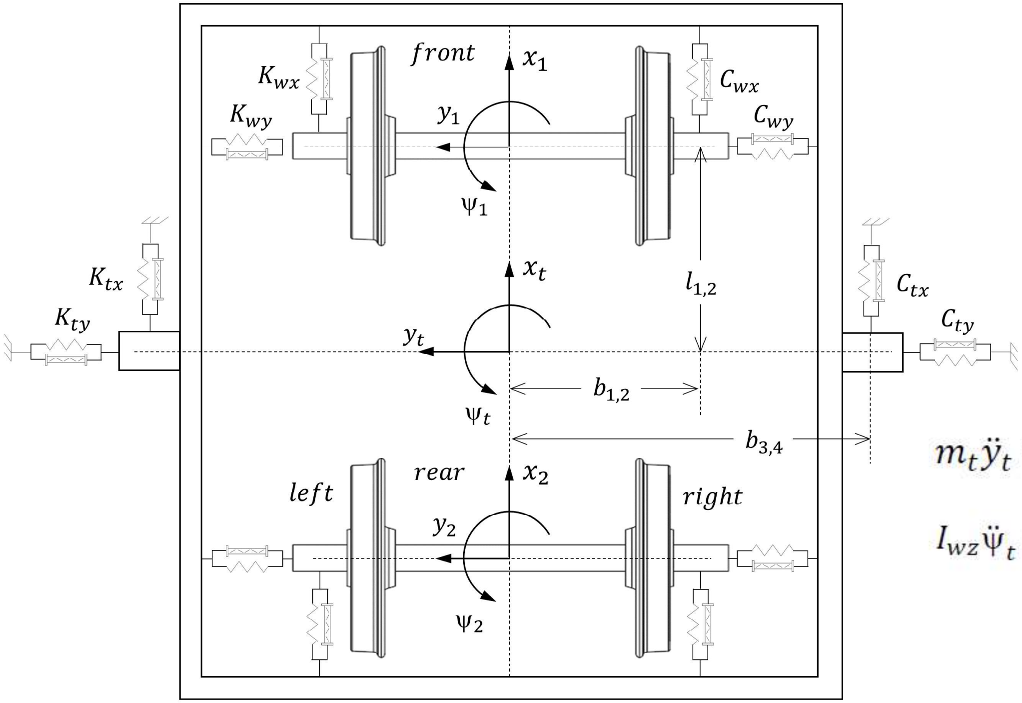
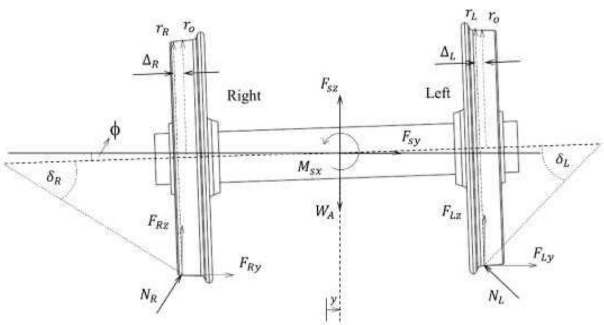
Vehicle acceptance analysis – Suspension parameters

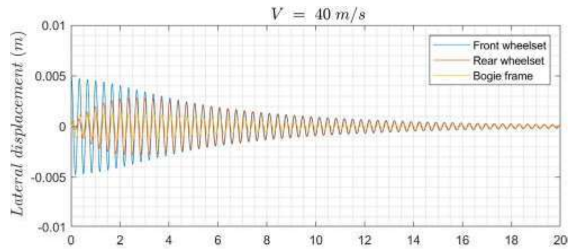


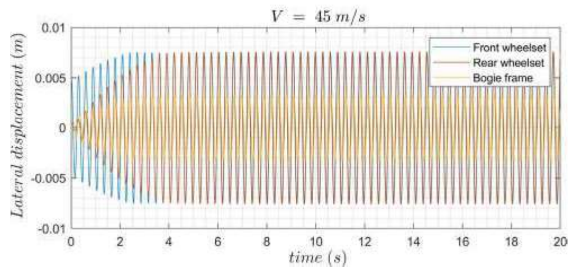


Parameter	K_{wy}	K_{wx}	K_{ty}	C_{ty}
SRC (β_x)	0.06311	0.60140	0.01177	0.06703
Parameter	λ		K_{tx}	C_{tx}
SRC (β_x)	- 0.76400		0.03967	0.21501

$$m_t\ddot{y}_t = -F_{sy1} - F_{sy2} - 2K_{ty}y_t - 2C_{ty}\dot{y}_t$$

$$\begin{aligned} I_{wz}\ddot{\psi}_t = &-2K_{wy}[y_1 - y_t + l_1\psi_t]l_1 \\ &+2K_{wy}[y_2 - y_t - l_1\psi_t]l_1 \\ &-2C_{wy}[\dot{y}_1 - \dot{y}_t + l_2\dot{\psi}_t]l_2 \\ &+2C_{wy}[\dot{y}_2 - \dot{y}_t - l_2\dot{\psi}_t]l_2 \\ &-2K_{tx}b_3^2\psi_t - 2C_{tx}b_4^2\dot{\psi}_t \\ &+2K_{wx}b_1^2(\psi_1 + \psi_2 - 2\psi_t) \\ &+2C_{wx}b_2^2(\psi_1 + \psi_2 - 2\dot{\psi}_t) \end{aligned}$$





Thanaporn Talingthaisong, Sedthawatt Sucharitpwatskul, Anchalee Manonukul, Panya Kansuwan, *Sensitivity Analysis of Suspension Parameters of the Critical Velocity of a Railway Bogie on a Tangent Track Using Standardized Regression Coefficients*, Journal of Engineering and Digital Technology, 2023. **11**(1).

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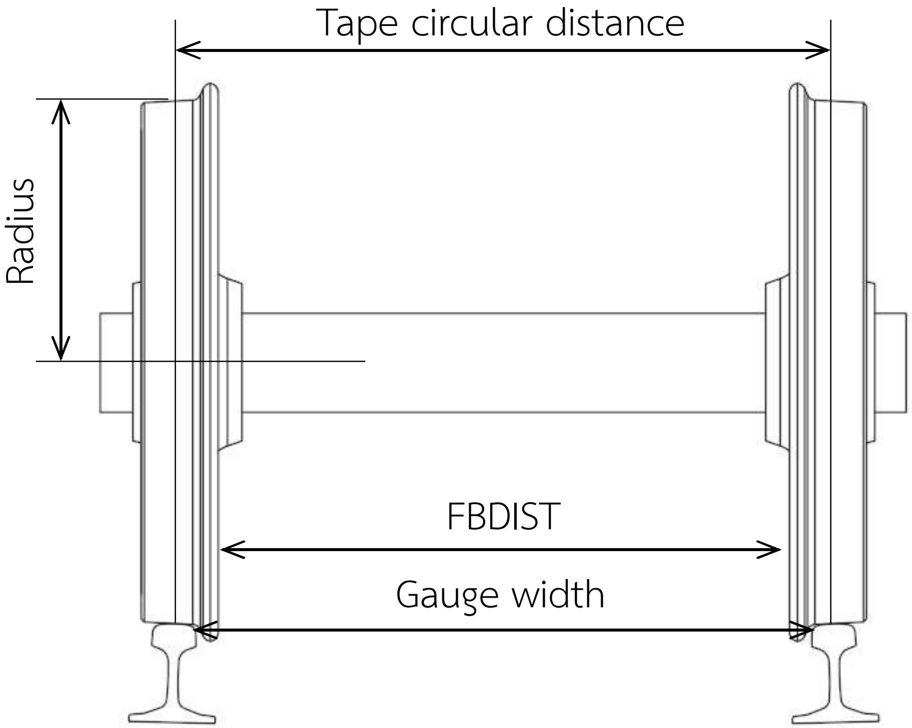
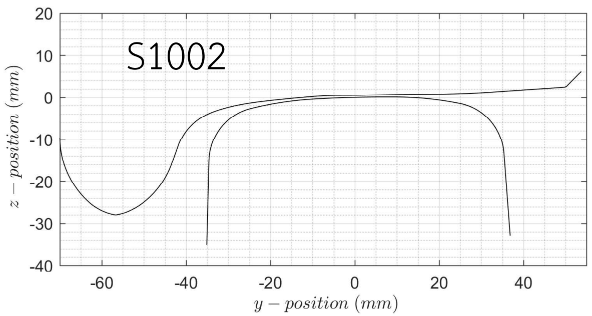
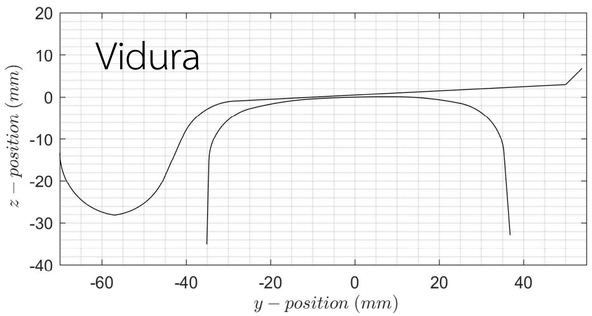
Vehicle acceptance analysis – Wheel/Contact pair geo-comparison



	Standard Gauge	Meter Gauge
Gauge width (mm)	1435	1000
Flange back distance (mm)	1360	927
Tape circular distance	1500	1067
Radius (mm)	460	425.5
Rail inclination	0.025	0.025
Wheel profile	S1002/h28.5/e30/70	Vidura/h28.5/e30/70
Rail profile	54E1	54E1





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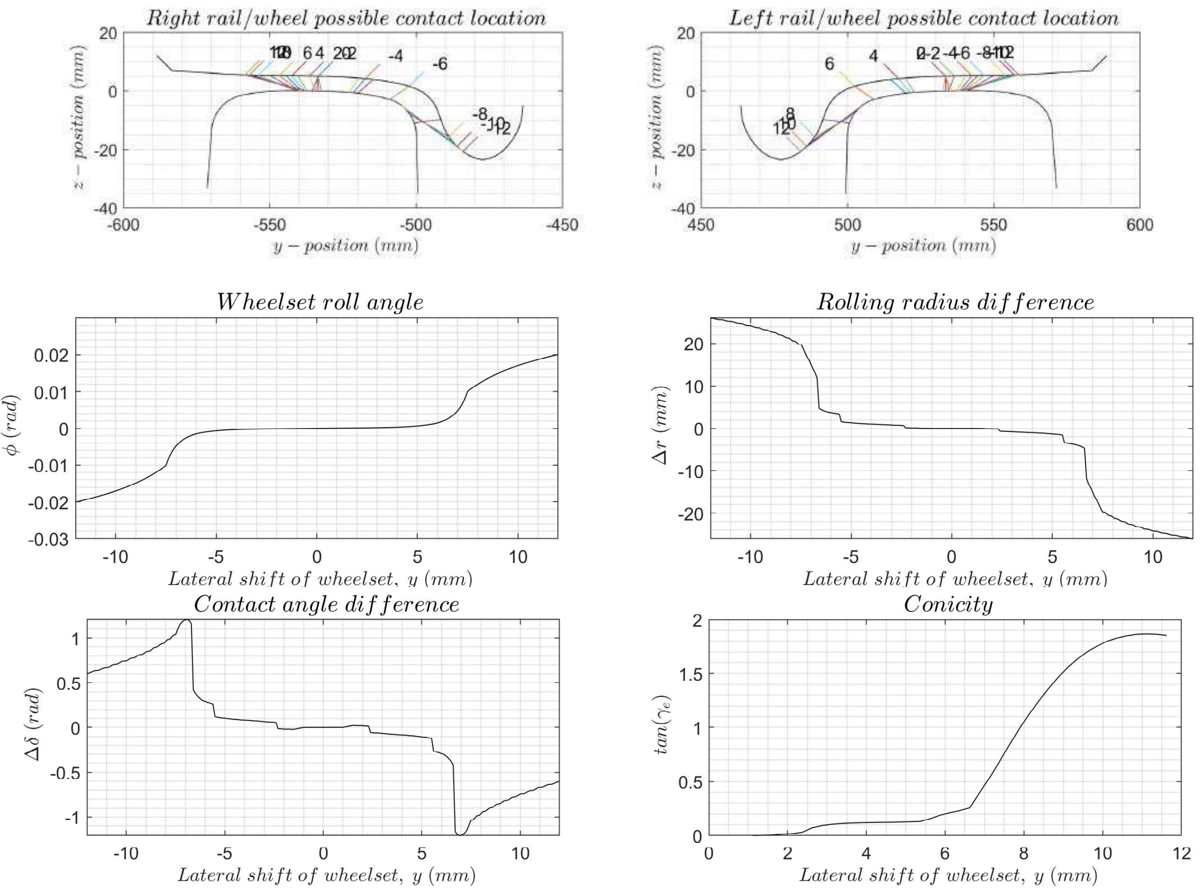
Vehicle acceptance analysis – Wheel/Contact pair geo-comparison

54E1-S1002/h28.5/e30/0.067/70



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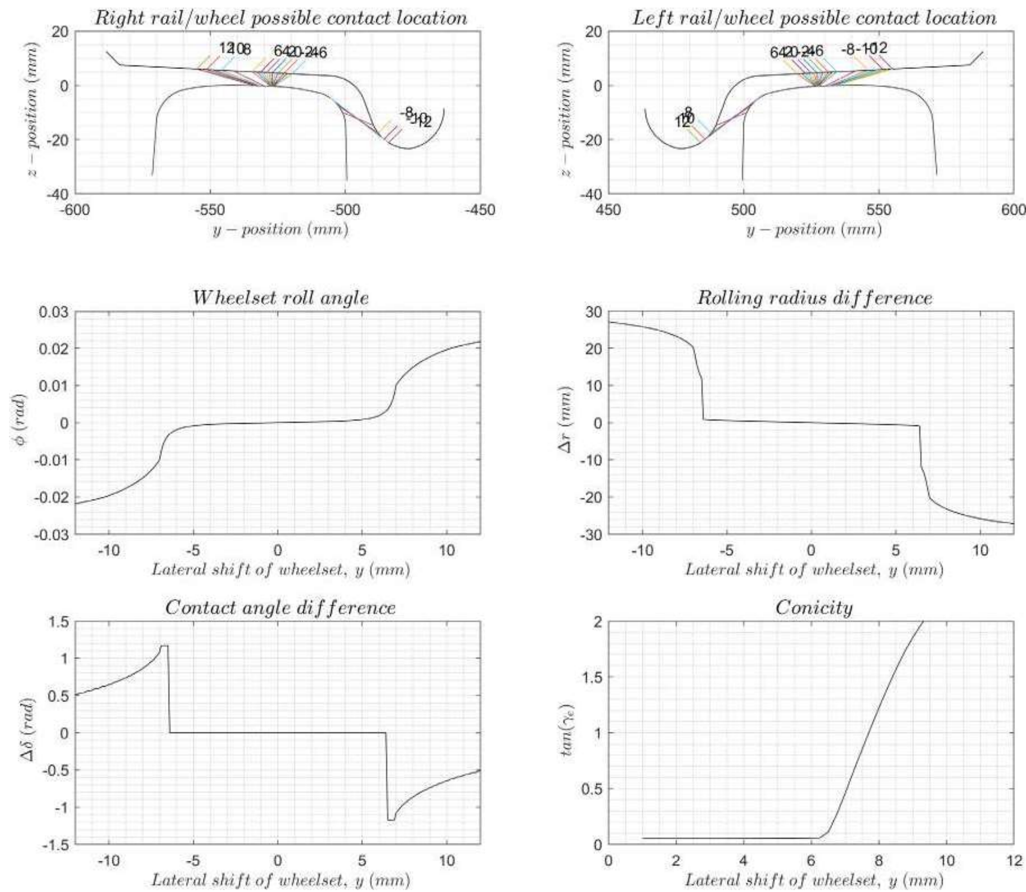

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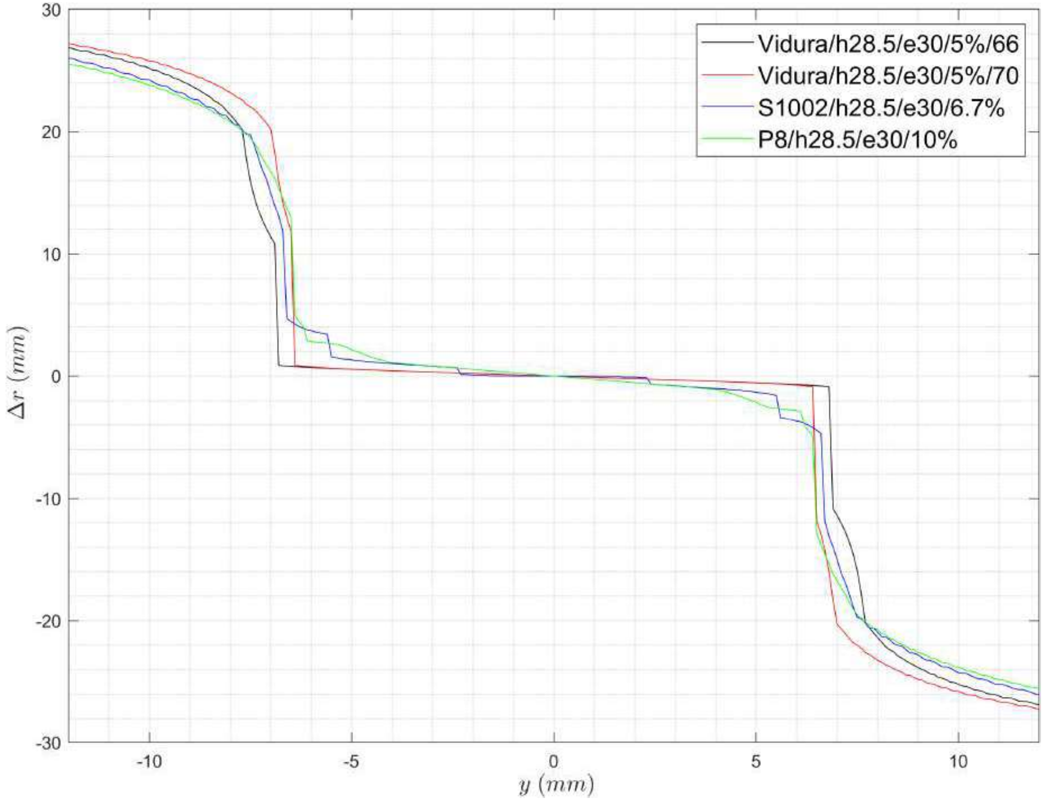
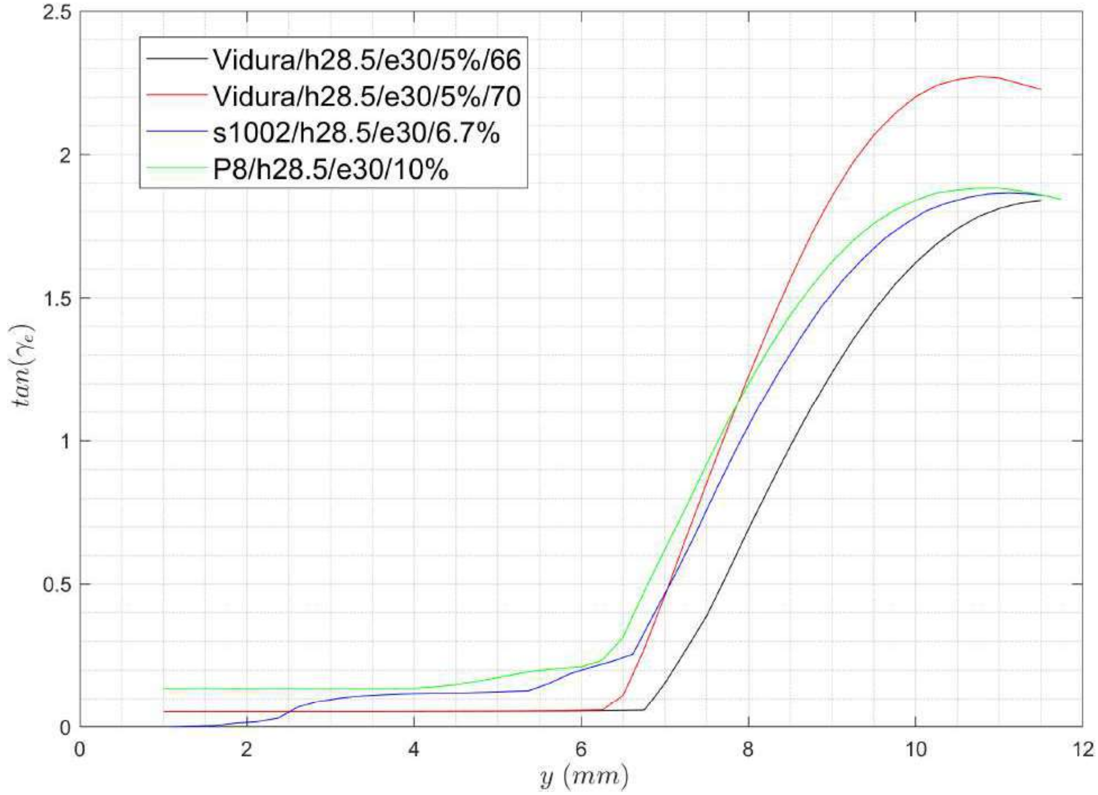
Vehicle acceptance analysis – Wheel/Contact pair geo-comparison





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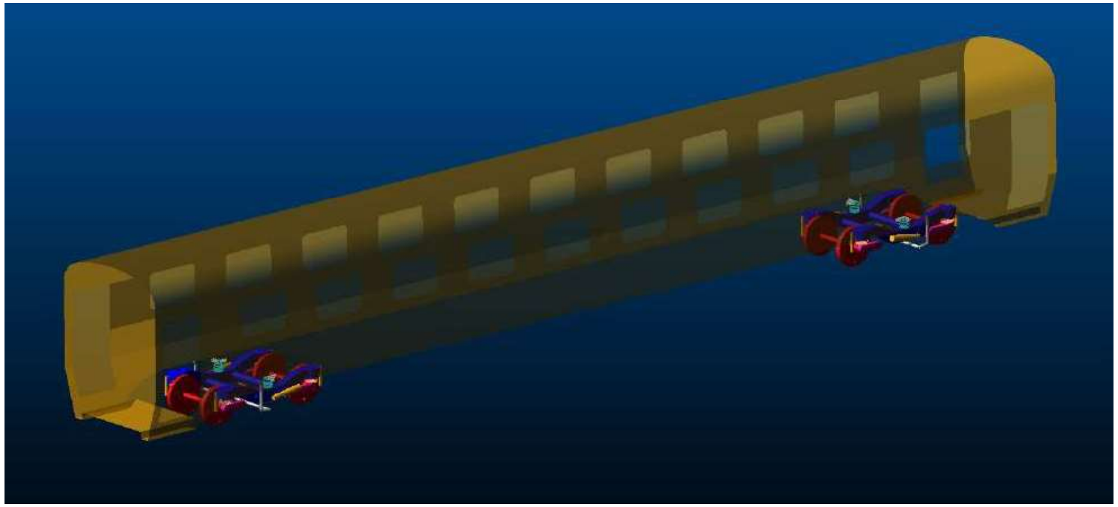
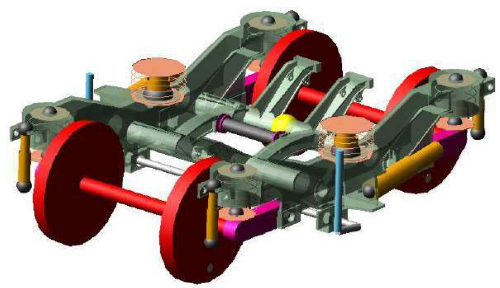
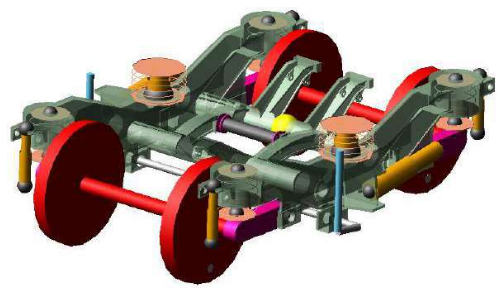
Vehicle acceptance analysis – Model parameters







Parameter	Symbol	Measure	Unit
Half of the track gauge	a	0.5	m
Wheel radius	r_o	0.4255	m
Wheelset mass*	m_w	932.09	kg
Moment of inertia of the wheelset – roll component*	I_{wx}	272.20	kg m^2
Moment of inertia of the wheelset – pitch component*	I_{wy}	73.15	kg m^2
Moment of inertia of the wheelset – yaw component *	I_{wz}	272.20	kg m^2
Axle load	W_A	1.01E+05	N
Mass of bogie frame	m_t	1212	kg
Moment of inertia of bogie frame in yaw	I_{tz}	1722	kg m^2
Primary suspension - Lateral stiffness	K_{wy}	6.17E+05	N/m
Primary suspension – Longitudinal yaw spring stiffness	K_{wx}	9.95E+05	N/m
Secondary suspension - Lateral stiffness	K_{ty}	1.60E+05	N/m
Secondary suspension - Lateral damping coefficient	C_{ty}	2.50E+04	N s/m
Secondary suspension - Longitudinal yaw spring stiffness	K_{tx}	1.60E+05	N/m
Secondary suspension - Longitudinal yaw damping coefficient	C_{tx}	2.50E+05	N s/m
Half of the primary longitudinal yaw spring arm	b	0.7875	m
Half of the primary longitudinal yaw damper arm	b_1	0.7875	m
Half of the secondary longitudinal yaw spring arm	b_2	0.7875	m
Half of the secondary longitudinal yaw damper arm	b_3	1.095	m
Half of longitudinal distance of the lateral secondary spring	l_1	1.15	m
Half of longitudinal distance of the lateral secondary dampers	l_2	1.15	m
Creep force coefficient – Lateral component	f_{11}	6.73E+06	N
Creep force coefficient – Spin component	f_{22}	1000	N m^2
Creep force coefficient – Lateral spin component	f_{12}	1.20E+03	Nm
Creep force coefficient – Longitudinal component	f_{33}	6.73E+06	N

Panya Kans

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Vehicle acceptance analysis – Model parameters and validation

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Title	Technical specification	Acceptance program
Party	Owner/Operator	Supplier
Responsibility	- Classification of the bogie type - All necessary documentation for design approval - Planning of activity to indicate that the design conform to the technical requirement and related norms. - Delivery of quality control process	- Design the bogie following the customer's specification - Activity to indicate that the design conform to the technical requirement and related norms. - Structural calculations for static assessment (bogie frame and attachment) - Structural calculations for fatigue assessment (bogie frame and attachment) - Static tests - Fatigue tests - On-track tests MSC Nastran · Adams · MSC Apex

category B-I bogies for main line and inter-city passenger carrying rolling stock including high speed and very high speed vehicles, powered and un-powered;

category B-II bogies for inner and outer suburban passenger carrying vehicles, powered and un-powered;

category B-III bogies for metro and rapid transit rolling stock, powered and un-powered;

category B-IV bogies for light rail vehicles and trams;

category B-V bogies for freight rolling stock with single-stage suspensions;

category B-VI bogies for freight rolling stock with two-stage suspensions;

category B-VII bogies for locomotives.

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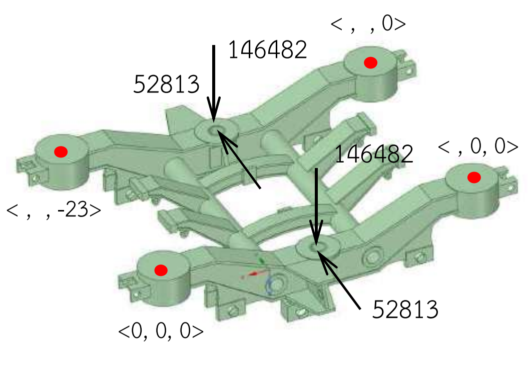
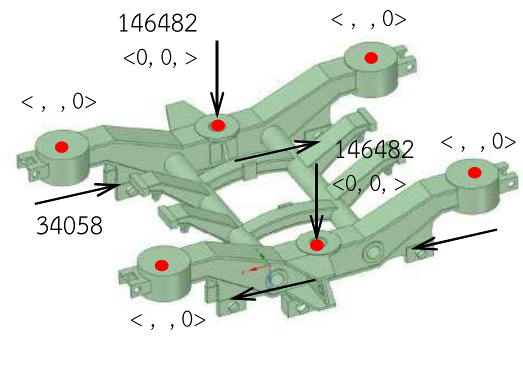
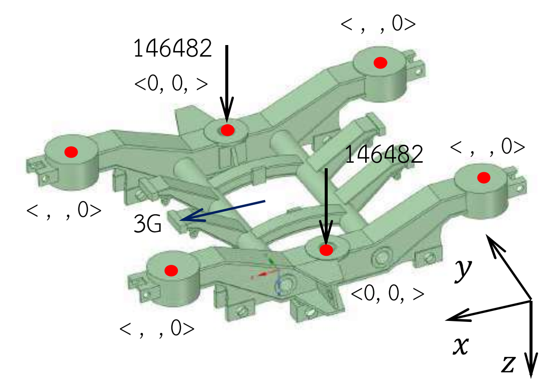
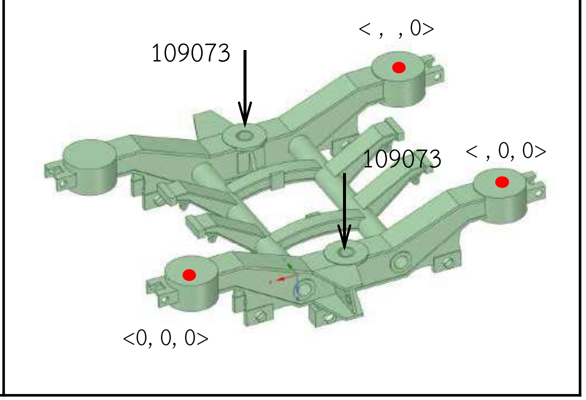
Vehicle acceptance analysis – Model parameters and validation

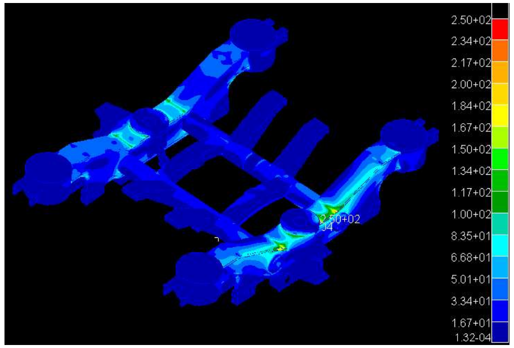
LC111 (ok)	LC112 (ok)	LC113 (ok)	LC114 (ok)
250	153	143	333

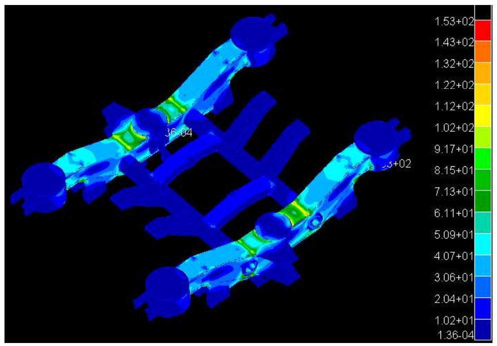


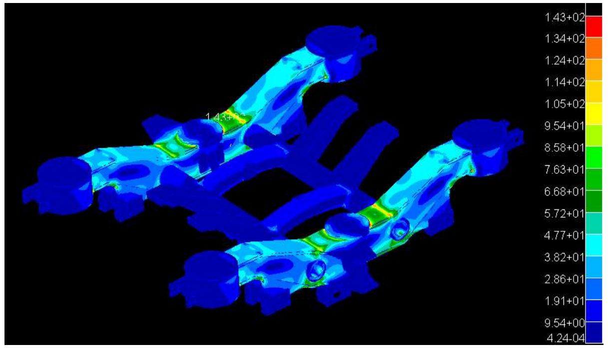


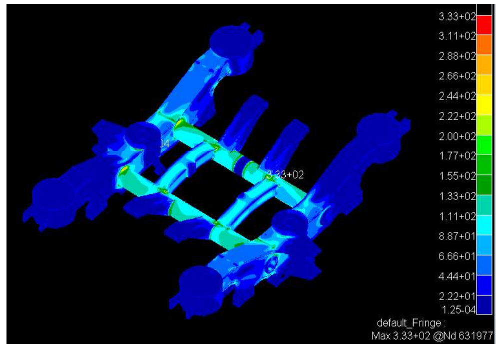












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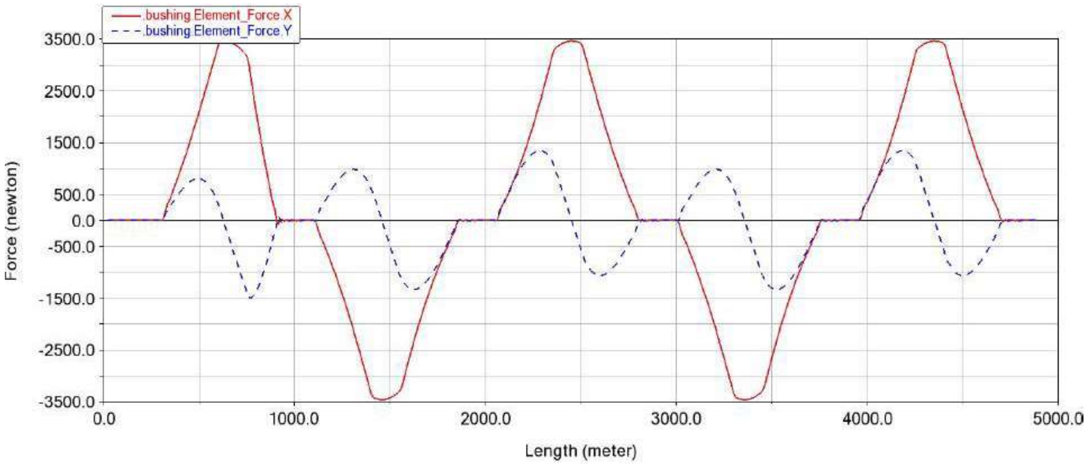

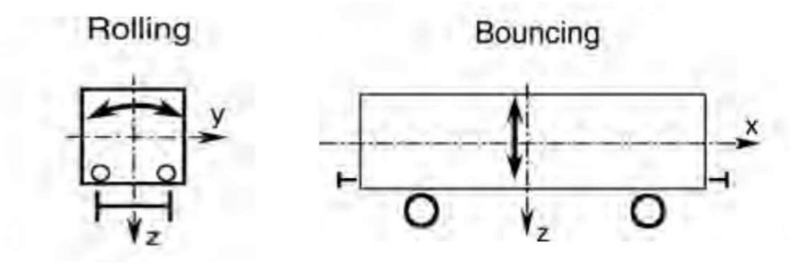

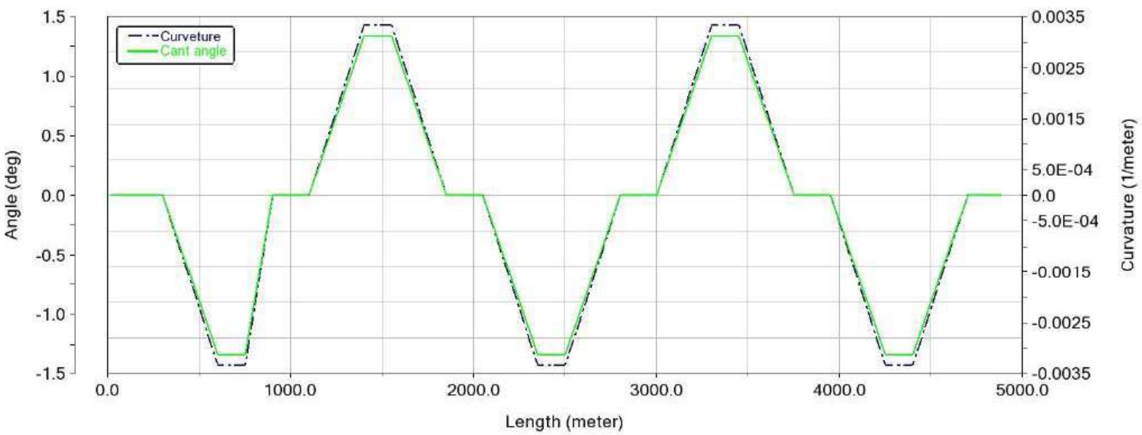

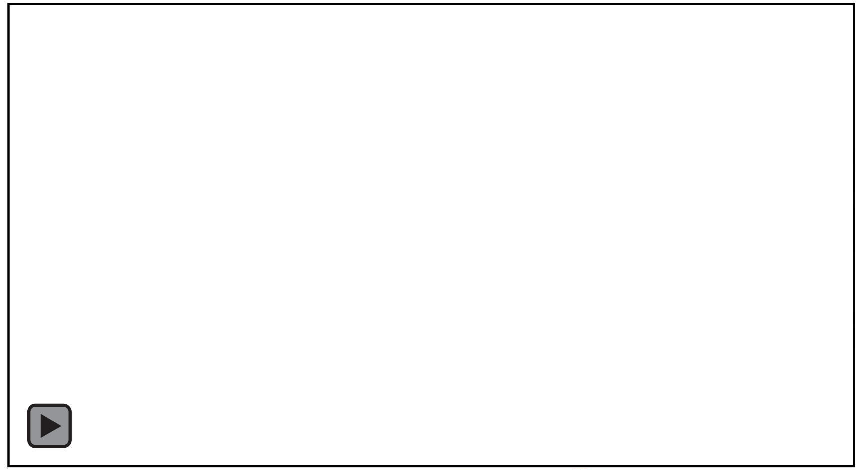

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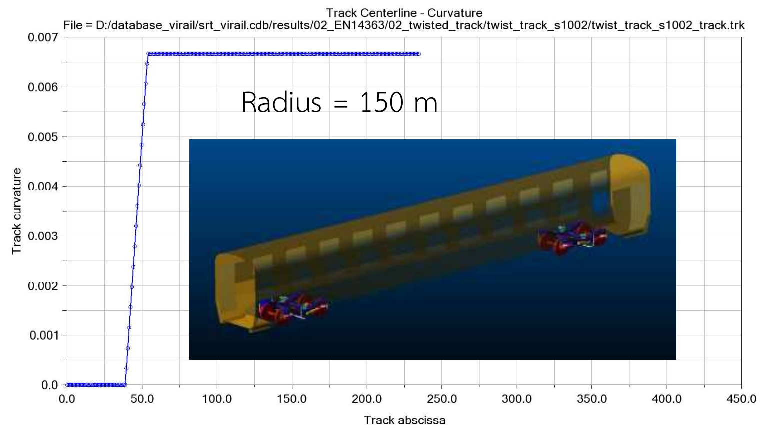
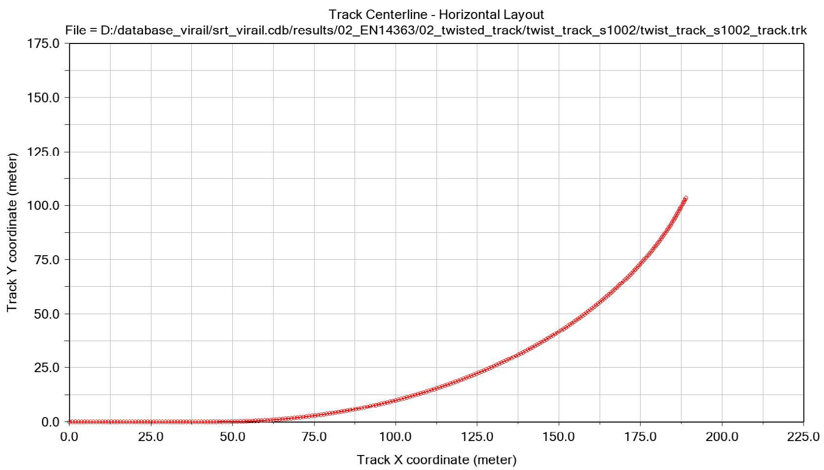
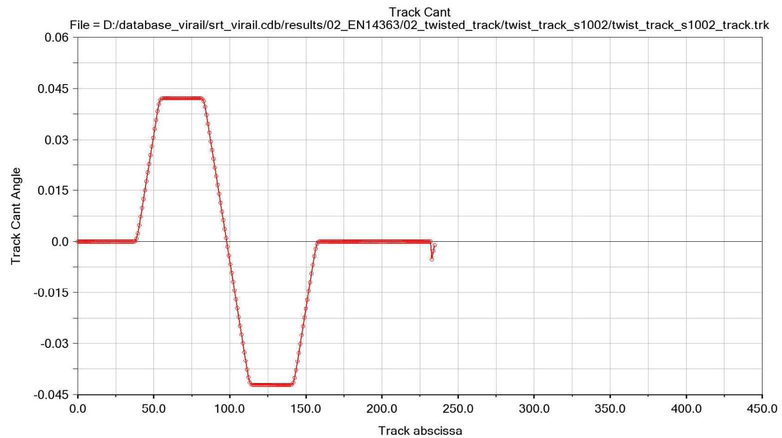
Vehicle acceptance analysis – Stationary test – Safety against derailment on twisted track







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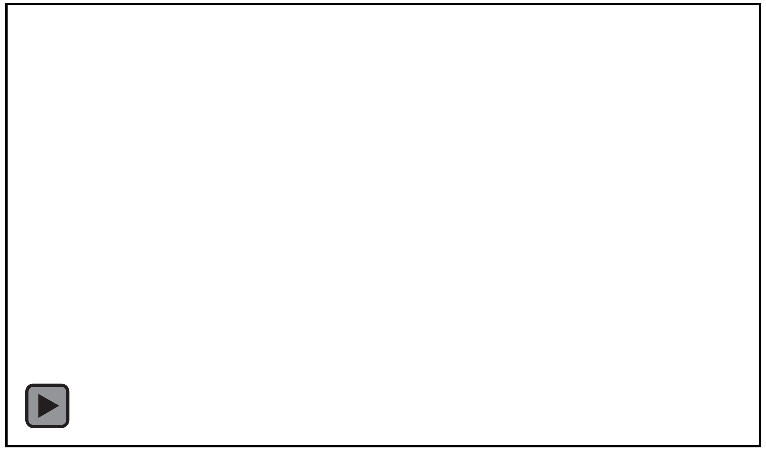
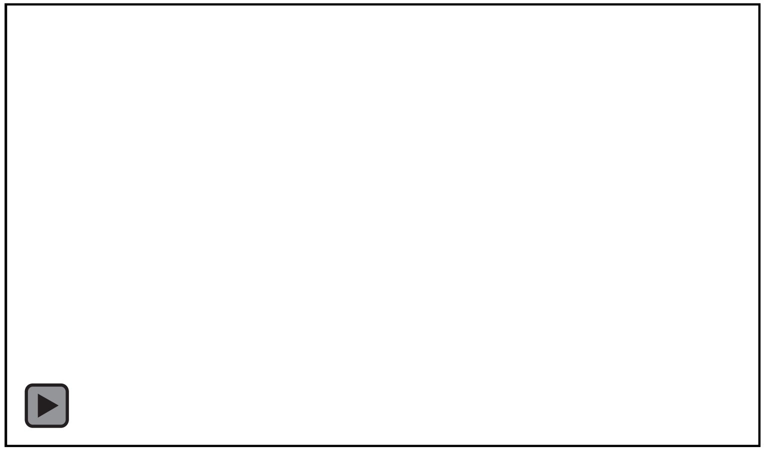
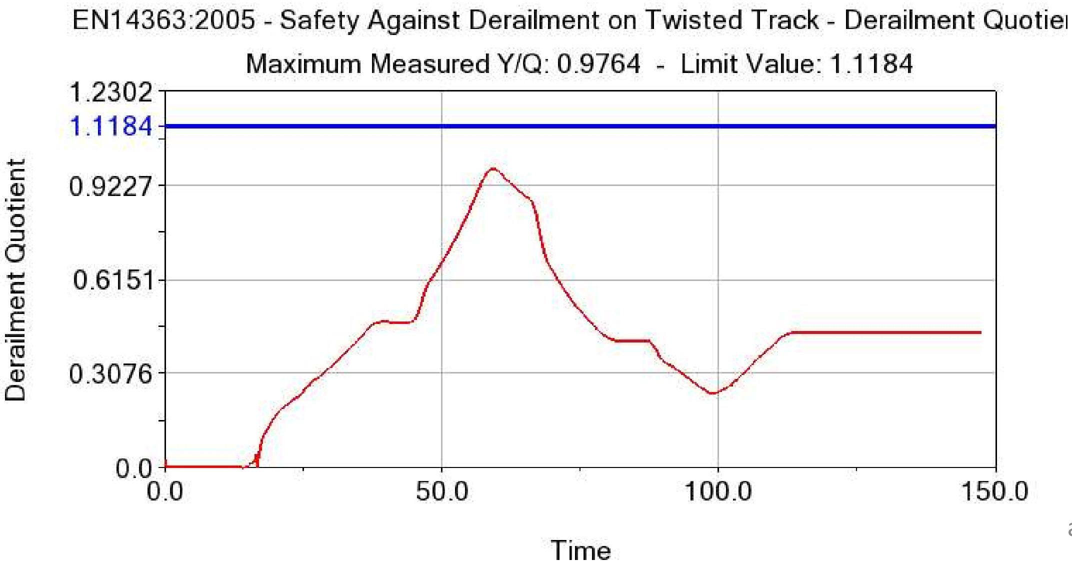
Vehicle acceptance analysis – Stationary test – Safety against derailment on twisted track







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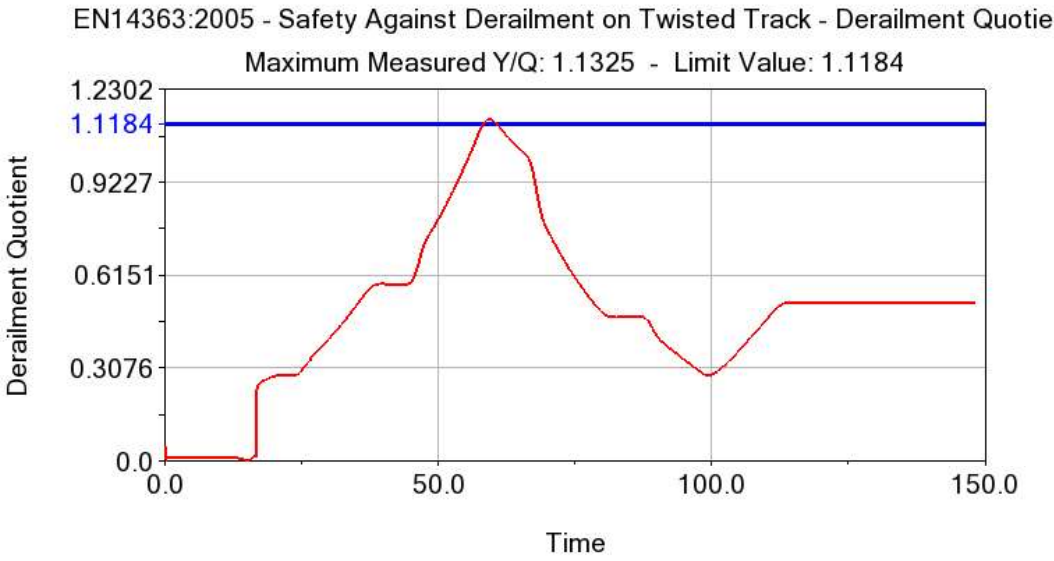
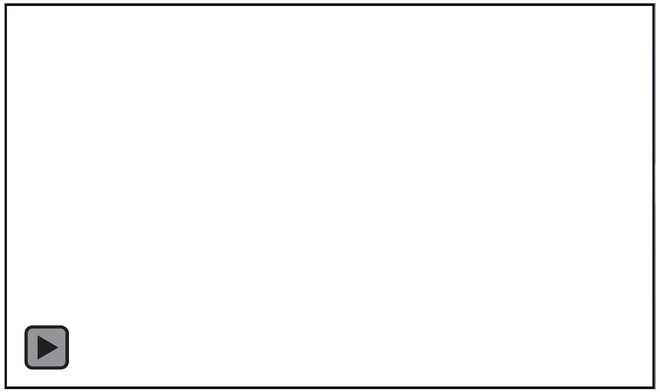
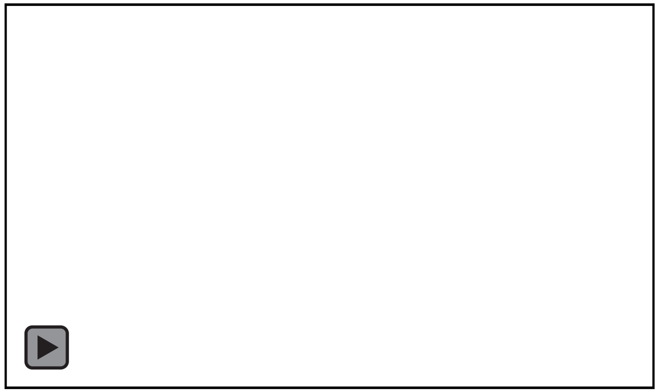
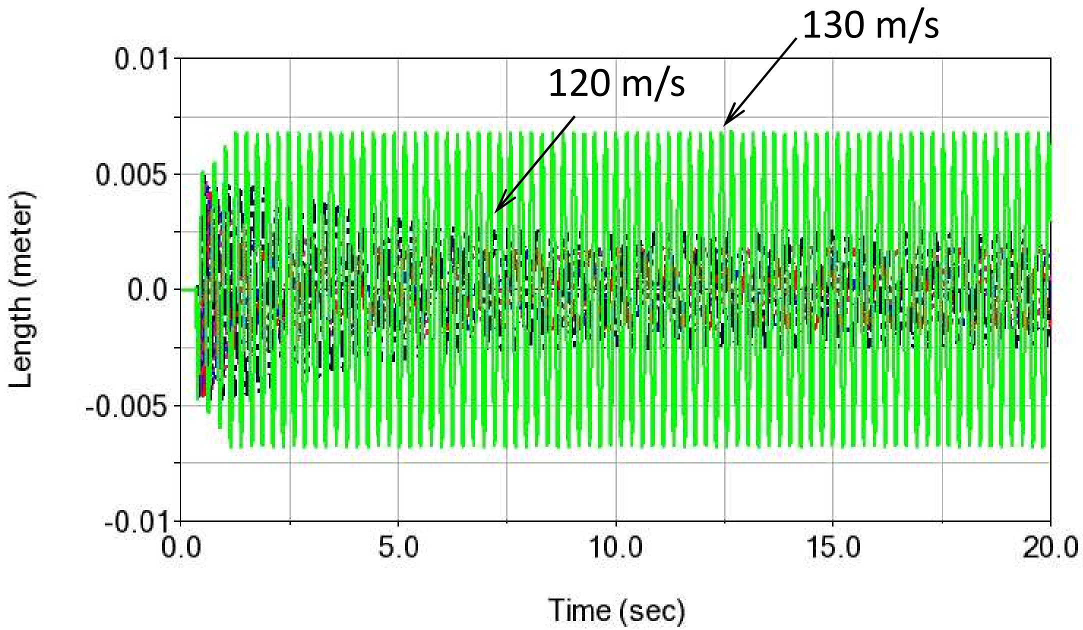


Computational simulation for understanding rail dynamics safety

Vehicle acceptance analysis – Estimation of critical velocity (Hunting motion)







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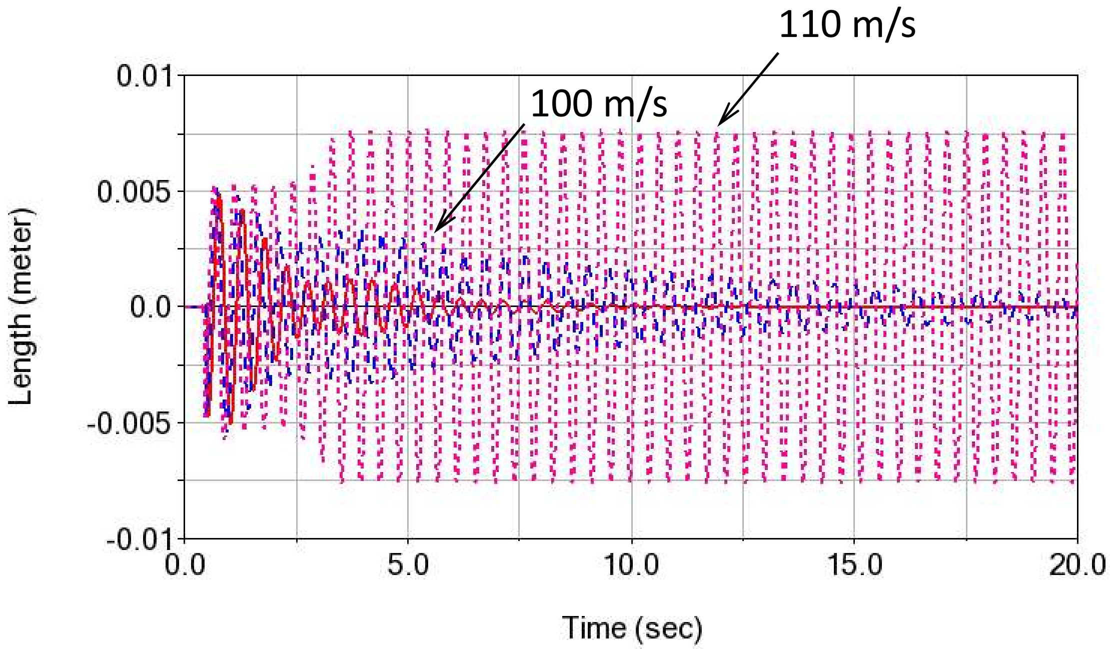

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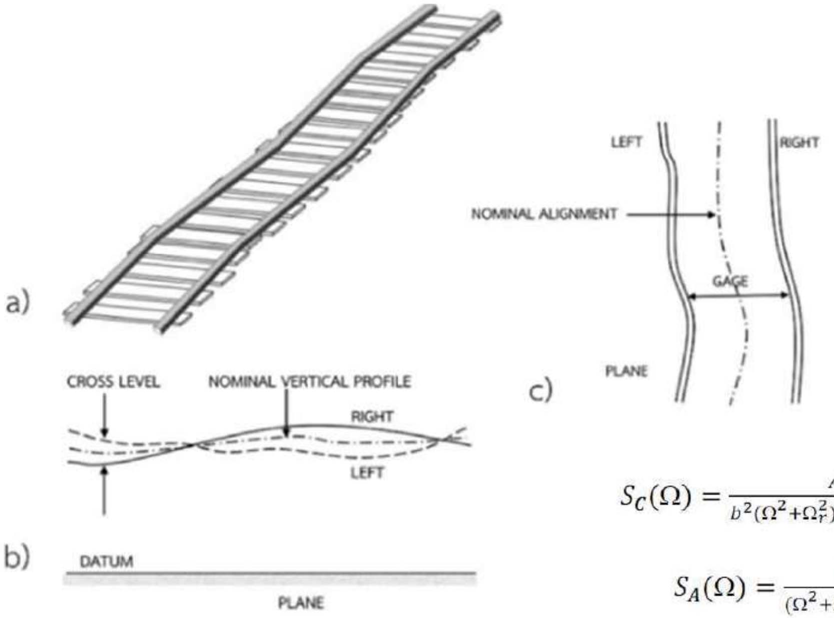
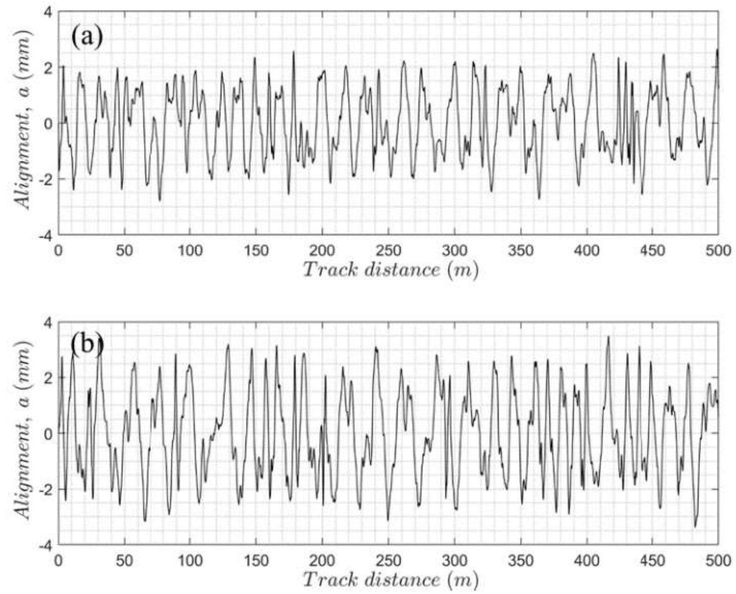


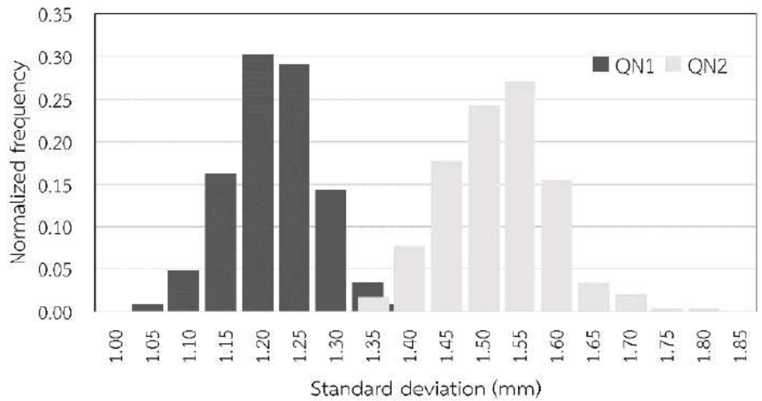
$$S_C(\Omega) = \frac{A_V \Omega_C^2 \Omega^2}{b^2(\Omega^2+\Omega_r^2)(\Omega^2+\Omega_C^2)(\Omega^2+\Omega_S^2)}$$

$$S_A(\Omega) = \frac{A_A \Omega_A^2}{(\Omega^2+\Omega_r^2)(\Omega^2+\Omega_C^2)}$$

$$S_V(\Omega) = \frac{A_V \Omega_A^2}{(\Omega^2+\Omega_r^2)(\Omega^2+\Omega_C^2)}$$

A_i	Lower	Higher
A_V $(m\,rad)$	4.032×10^{-7}	1.080×10^{-6}
A_A $(m\,rad)$	2.119×10^{-7}	6.124×10^{-7}





Panya Kansuwan, Sedthawat Sucharitpwatskul, A. Manonukul,"Application of Fast Fourier Transform to the Synthesis of Track Irregularities," in *the 8th International Conference on Engineering, Applied Sciences and Technology (ICEAST 2022)*. 2022: Online.

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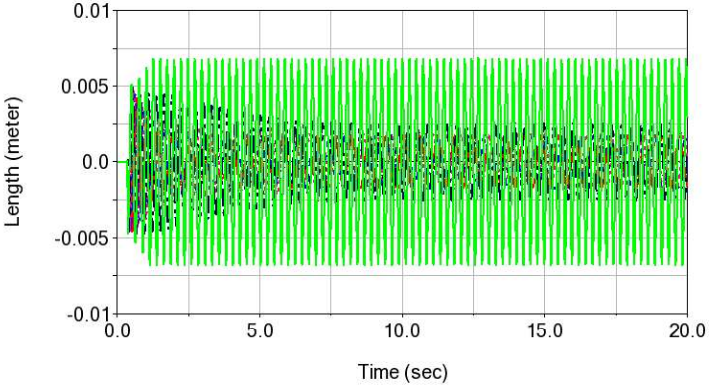
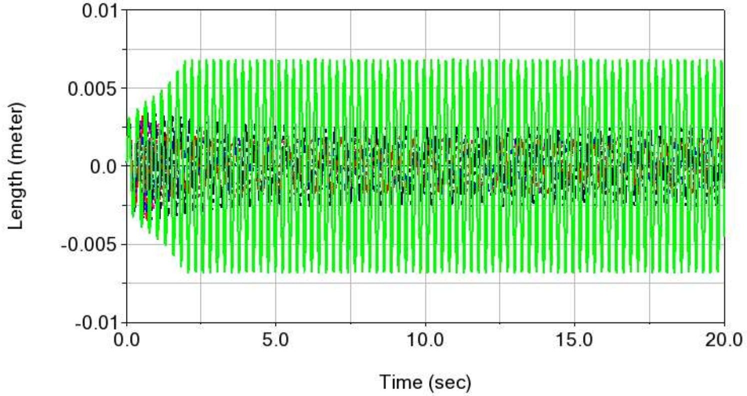
Vehicle acceptance analysis – Estimation of critical velocity (Hunting motion)

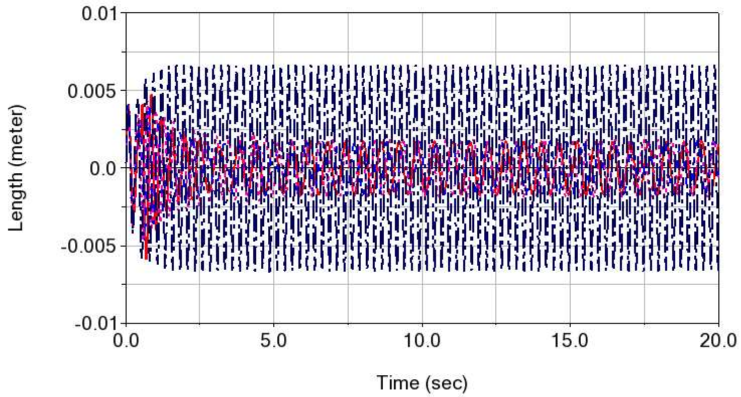
130 m/s



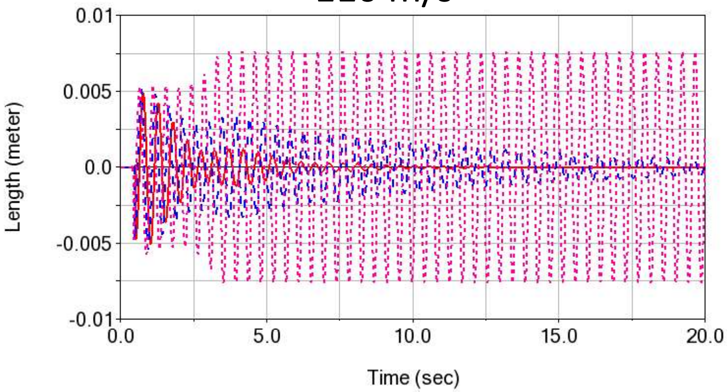
130 m/s



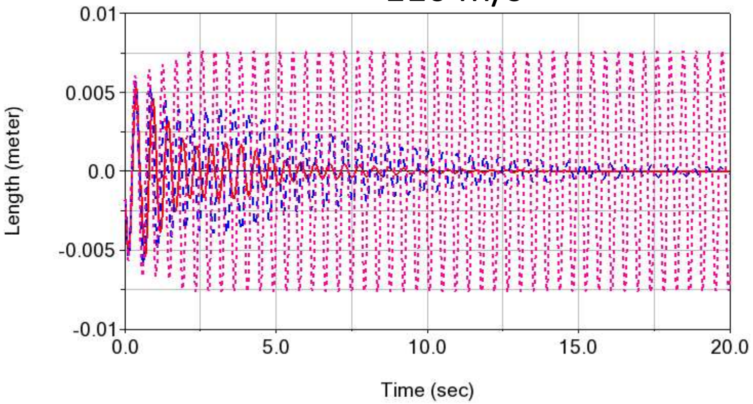
120 m/s



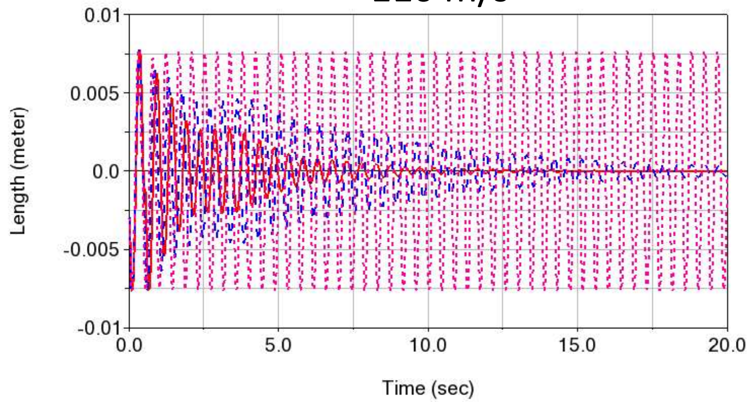
110 m/s



110 m/s



110 m/s



Computational simulation for understanding rail dynamics safety

Vehicle acceptance analysis – Estimation of critical velocity (On-track test)

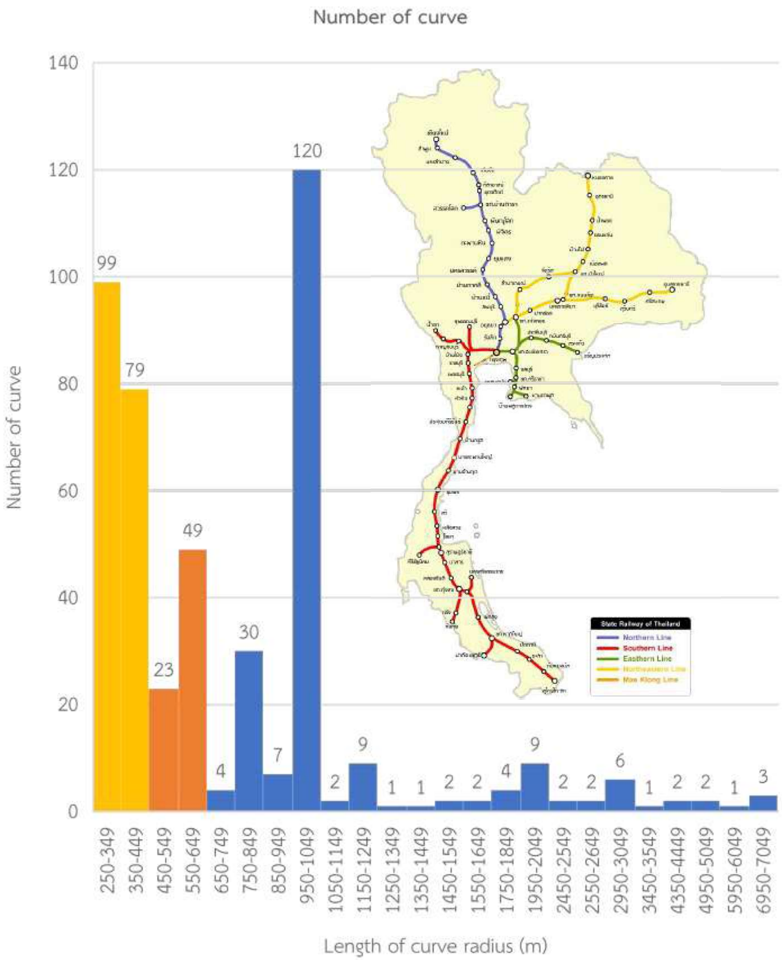
EN14363 : 2005

Test element

- Assessment of vehicle parameter relevant to running characteristics
  - Broad assessment base on design characteristics
- Primary approval
  - Stationary tests
    - Safety against deraiement on twisted track (exists in the VI-rail)
    - Sway characteristics
    - Safety against derailement under longitudinal forces in S-shaped curve
    - Bogie rotational resistance
    - Measurement of static wheel force (exists in the VI-rail)
- Testing of running behavior
  - On-track test
    - complete on-track test
      - normal measuring method
      - simplified measuring method
    - partial on-track test
      - normal measuring method
      - simplified measuring method

Computational simulation for understanding rail dynamics safety

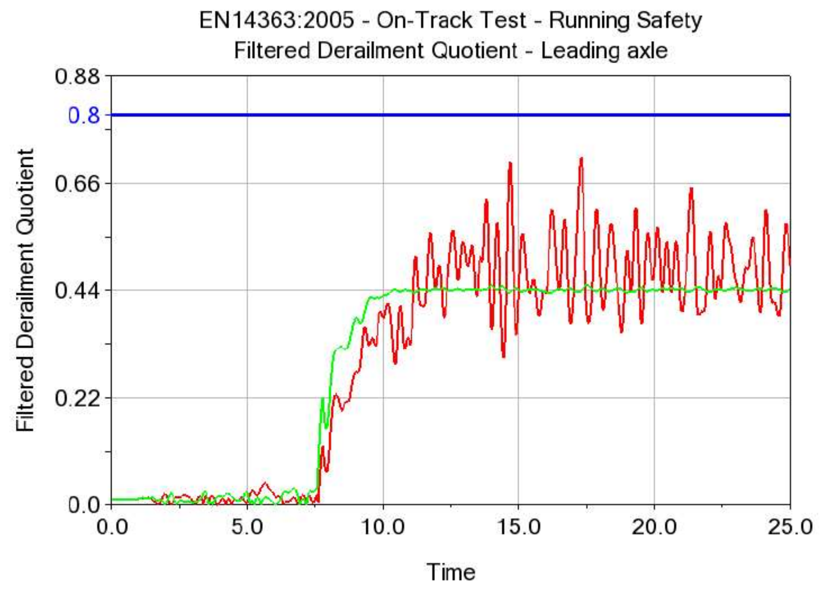
Vehicle acceptance analysis – Estimation of critical velocity (On-track test)



Test Zone	1	2	3	4
	Straight Track and curves with very large radius	Large-radius curves	Small-radius curve	Very small-radius
Radius of circular curves (m)	$R \geq 8000$	$600 \leq R \leq 3000$	$400 \leq R \leq 600$	$250 \leq R \leq 400$
Track length (m)	615477	68066	22975	44905
Length fraction (%)	81.91	9.06	3.06	5.98
Number of Curves	15	195	72	178
Number fraction (%)	3.26	42.39	15.65	38.70

Searching for safe operation range

loadcase	Test zone	Test zone	Speed (km/h)	Speed (m/s)	Curve radius (m)
1	4	44	40	11.11	250
2		43	40	11.11	300
3		42	40	11.11	350
4		41	40	11.11	400
5	3	35	60	16.67	450
6		34	60	16.67	500
7		33	60	16.67	550
8		32	60	16.67	600
9		31	60	16.67	700
10	2	30	80	22.22	800
11		29	80	22.22	900
12		28	90	25.00	1000
13		27	90	25.00	1100
14		26	90	25.00	1200
15		25	90	25.00	1300
16		24	90	25.00	1400
17		23	100	27.78	1500
18		22	120	33.33	2000
19		21	120	33.33	4000
20	1	13	120	33.30	8000
21		12	120	33.30	10000
22		11	120	33.33	infinity



Computational simulation for understanding rail dynamics safety
Vehicle acceptance analysis – Estimation of critical velocity (On-track test)

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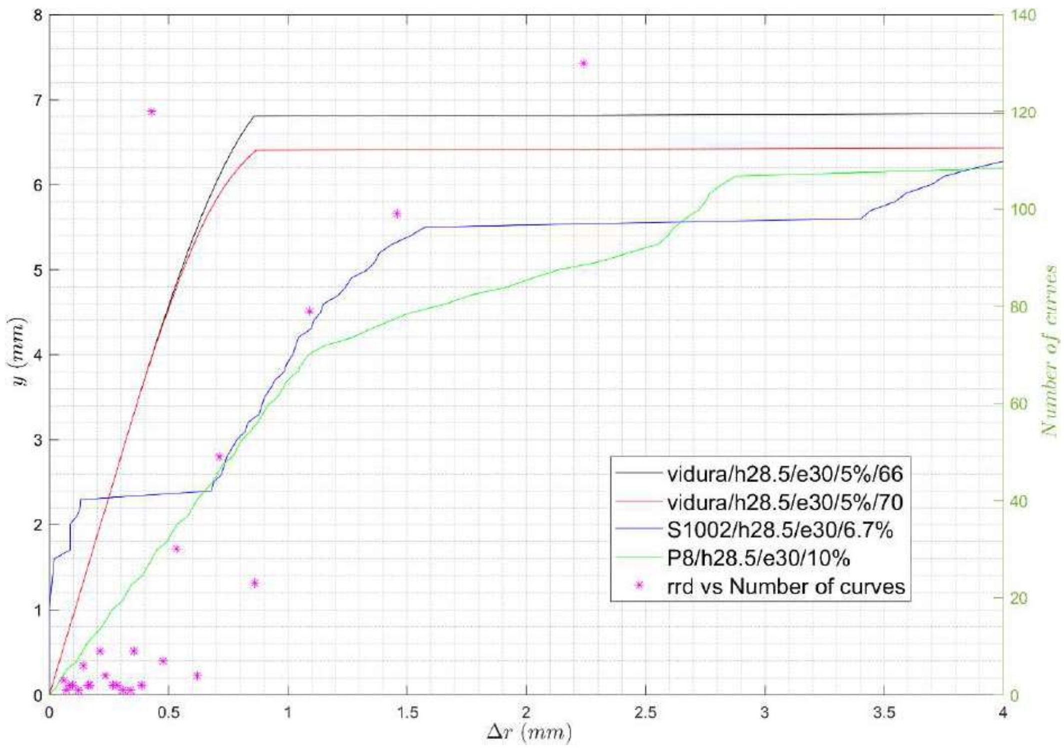
Vehicle acceptance analysis – Estimation of critical velocity (On-track test)

Target rolling radius difference (TRRD)

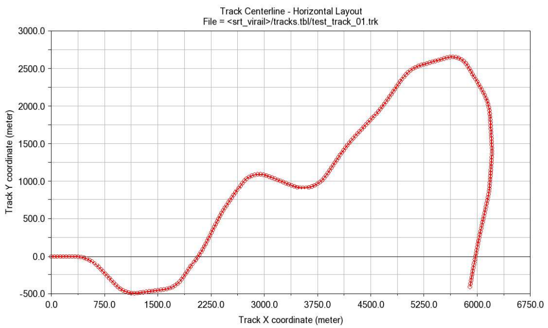


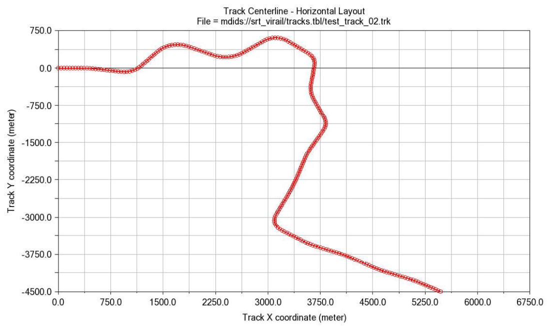
รัศมีโค้ง (m)	RRD	จำนวนโค้ง	รัศมีโค้ง (m)	RRD	จำนวนโค้ง
190	3.63	130	1500	0.46	2
292	2.36	99	1600	0.43	2
390	1.77	79	1800	0.38	4
494	1.40	23	2000	0.35	9
597	1.16	49	2500	0.28	2
687	1.00	4	2600	0.27	2
798	0.86	30	3000	0.23	6
892	0.77	7	3500	0.20	1
994	0.69	120	4400	0.16	2
1100	0.63	2	5000	0.14	2
1200	0.58	9	6000	0.12	1
1250	0.55	1	7000	0.10	3
1380	0.50	1	15000	0.46	2

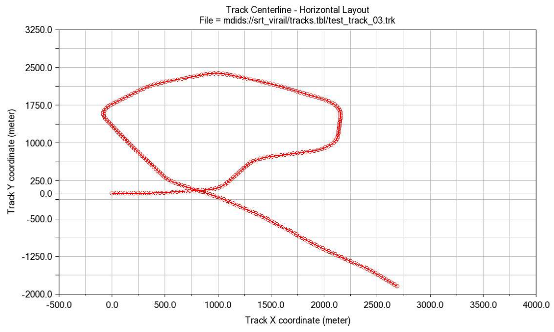
$$\Delta r = \frac{2br}{R}$$

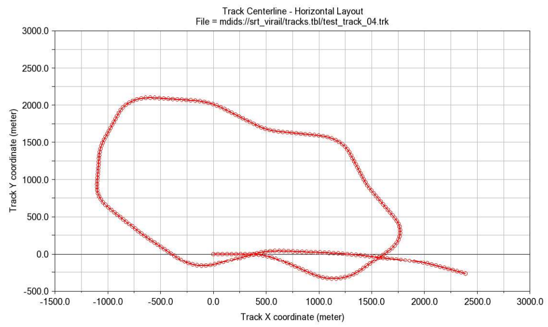
Computational simulation for understanding rail dynamics safety

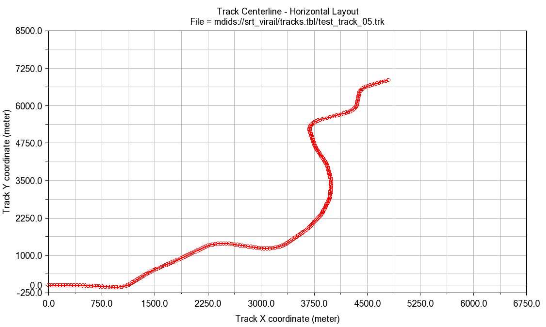
Vehicle acceptance analysis – Estimation of critical velocity (On-track test)

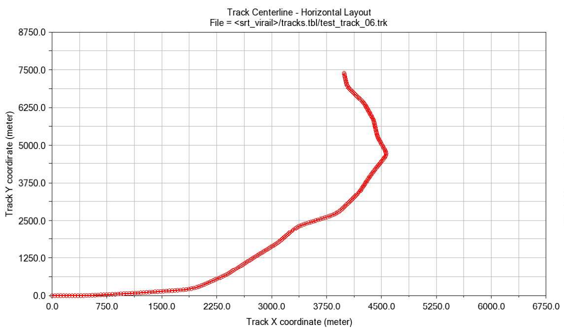


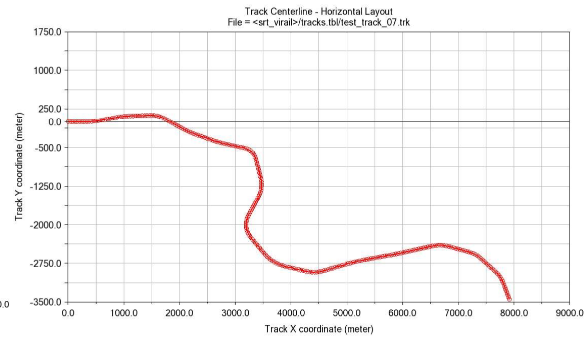


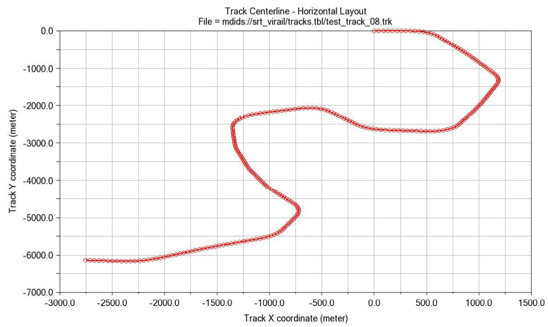






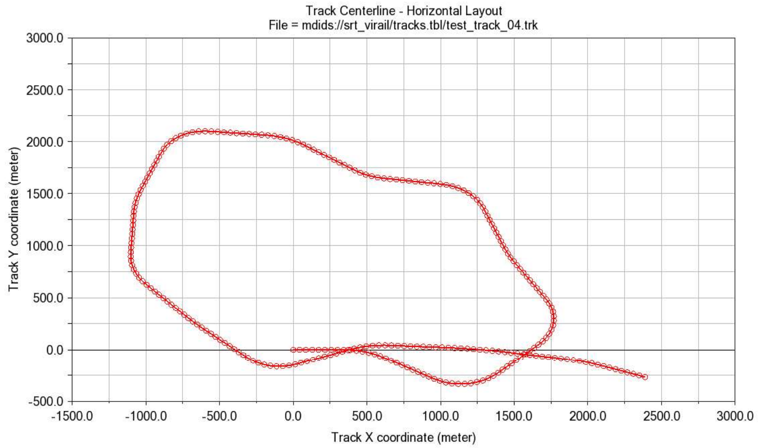


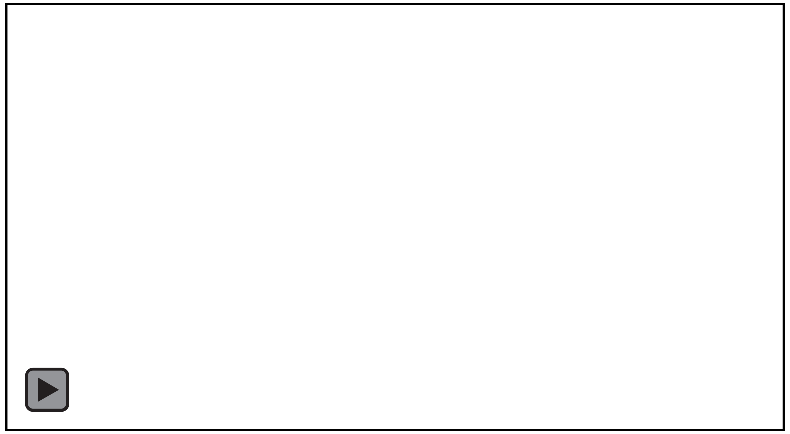


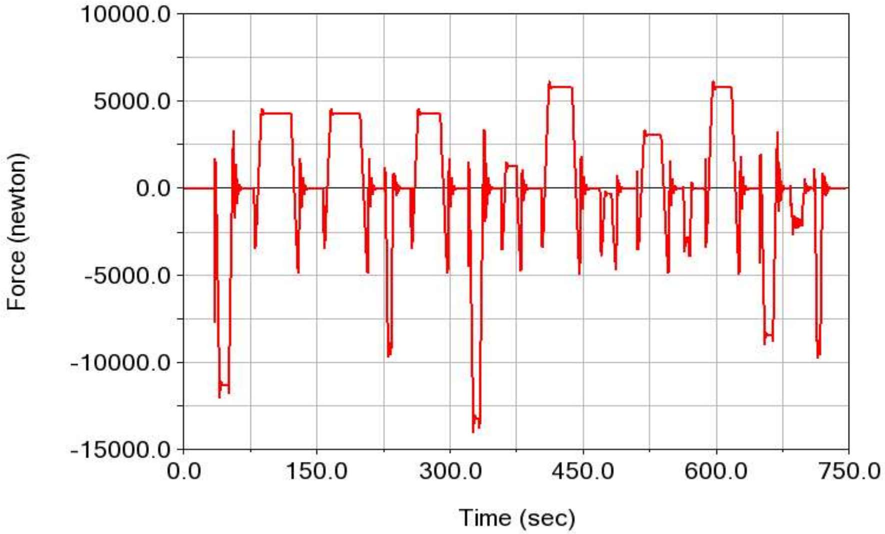


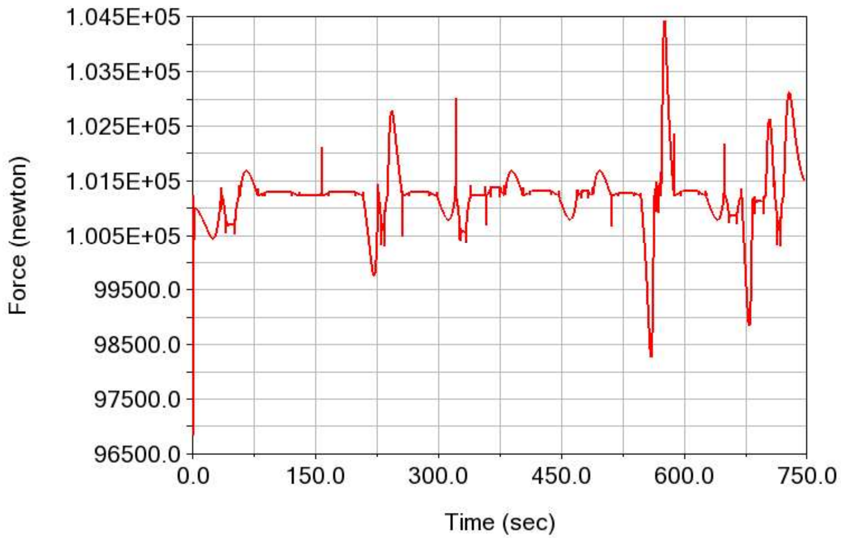
Computational simulation for understanding rail dynamics safety

Vehicle acceptance analysis – Estimation of critical velocity (On-track test)









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Vehicle acceptance analysis – Estimation of critical velocity (On-track test)

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