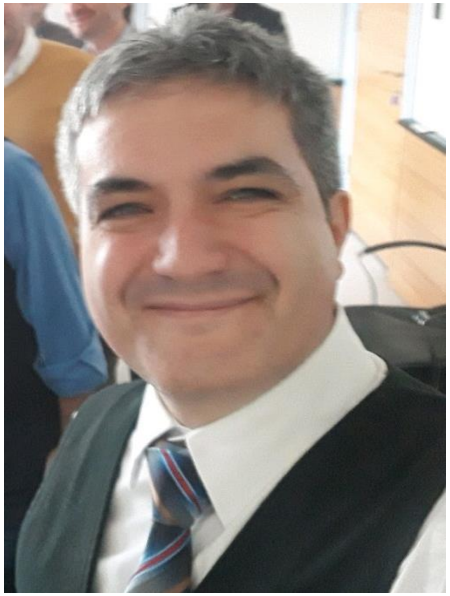

Dr. Niyazi <u>Özgür</u> Bezgin

Associate Professor in Civil Engineering
Istanbul University – Cerrahpaşa

Concentration on:
1. *Design of prefabricated structures*
2. *Soil and structure interaction*
3. *Railway track mechanics*

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Discovered a new-found interest in learning to play the double-bass. Looking forward to giving a concert to ICRI members in Istanbul.

Spending part of the pandemic days with my telescope on my balcony during clear nights which we had many this summer.

The International Collaborative Research Initiative on Rolling Contact Fatigue and Wear of Rails and Wheels

"Introduction of Bezgin-Kolukırık Equations to estimate peak dynamic impact forces caused by wheel flats and the introduction of the worksheet titled ALLTRACK v2"

Niyazi Özgür Bezgin, Ph.D

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November 3, 2020

22.00 Istanbul

Wheel flats

- A wheel flat is a discrete type of wheel out-of-roundness and is a wheel tread defect.
- A deviation from the nominal wheel radius occurs at a wheel flat, which is relatively much shorter in length with respect to the wheel circumference.
- This deviation can generate a significant dynamic impact force on railway track, relating to the length of the flat, the diameter of the wheel, the speed of the train, the static wheel force and the equivalent stiffness of the rolling stock-railway track system.

http://www.mermecgroup.com/inspect/train-monitoring/1024/wheel-impact-load.php

https://ar-tech.com.au/wheel-brake-monitoring/

Adverse effects of wheel flats

- The interaction of the wheel flat with the railhead is a highly indeterminate problem.
- This interaction before the impact and after the impact generates dynamic impact forces with high frequency and low frequency content that decays and repeats with each revolution of the wheel.
- The peak forces can reach to ~4 times the static wheel forces that can lead to railhead and wheel plastification and RCF.
- The condition is further complicated with the fact that the formation of the wheel flat can change the crystalline phase of the both the wheel at the vicinity of the flat and the rail due to high temperatures that can occur during sliding.
- Therefore, damage caused by the wheel flat can be both mechanical and thermal.

Adverse effects of wheel flats

- At the minimum, wheel flats generate noise and vibrations.
- In the worst case, the high dynamic impact forces that develop can damage the railhead and the wheel.
- The complicated nature of the interaction calls for advanced time iterative numerical methods of analysis on mechanical models and/or detailed instrumentation along actual railways and on trains.

The first paper where the proposed method was introduced

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 189 (2017) 2 – 10

Procedia Engineering

www.elsevier.com/locate/procedia

Transportation Geotechnics and Geoecology, TGG 2017, 17-19 May 2017, Saint Petersburg, Russia

Development of a new and an explicit analytical equation that estimates the vertical impact loads of a moving train

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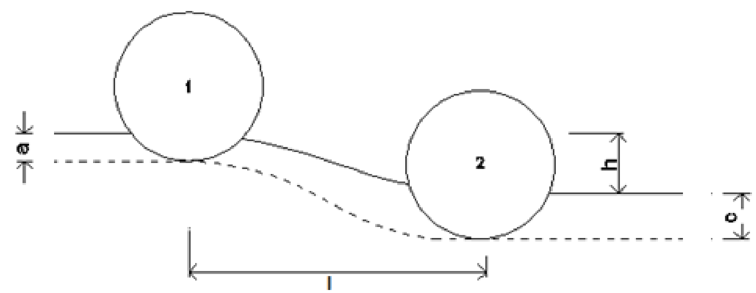
Abstract

One can only estimate the dynamic vertical impact loads under motion, since there are many effective parameters some of which are unrepresented in an equation and since the values of the considered parameters are not deterministic but estimations. Many empirical and semi-empirical equations in the literature correlate dynamic impact loads to train speed and measurable aspects of train and track components. These aspects frequently relate to track and train geometry and stiffness. However, the development of these equations relies on load and deflection measurements from particular in-service tracks or especially set-up test tracks. The constants that frequently appear in these equations are particular to the conditions that generated them. Therefore, one lacks an explicit understanding of these equations unless one takes the time to investigate in detail the particular study and the particular set of data that generated these equations. Train speed limits also bound the applicability of these equations. This paper concentrates on the development of an explicit mathematical equation aimed to provide an explicit analytical estimate for the dynamic impact loads that develop on any railway track by the axles of a moving train. This paper introduces the concept of impact reduction factor and introduces a new equation that relies on the principle of conservation of energy and kinematic principles along with the impact reduction factor to estimate the impact loads generated by a moving train.

Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology.

Keywords: Train speed; track stiffness; track deformation; dynamic impact load; impact load factor.



Bezgin Method: An analytical approach that offers support to the engineer/researcher, before he or she resorts to more advanced methods

- The proposed method has been applied to track roughness in the form of track profile variation and track stiffness variation.

- When applied to wheel flats, it yields an explicit analytical approach that considers the effects of the following parameters on the dynamic impact forces due to wheel flats:

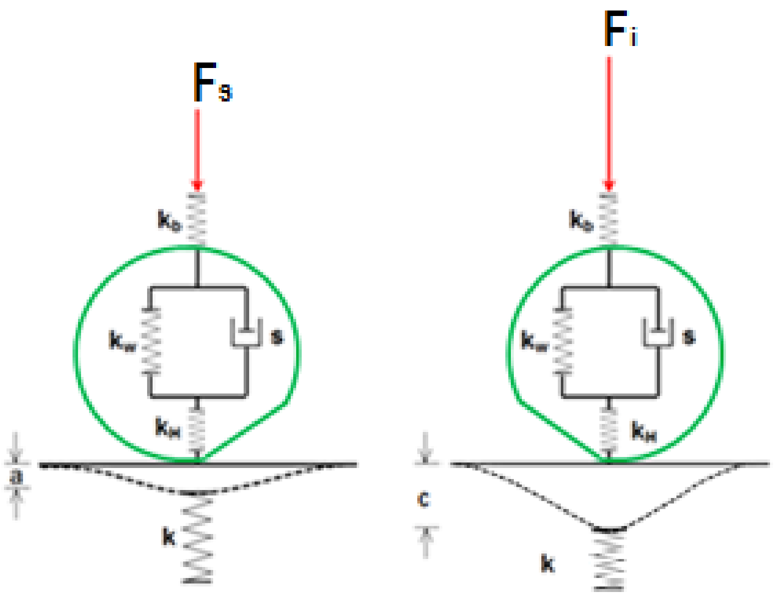
1. Wheel flat length
2. Wheel diameter
3. Train speed
4. Track stiffness
5. Primary and secondary spring stiffness'
6. Hertzian contact deformation

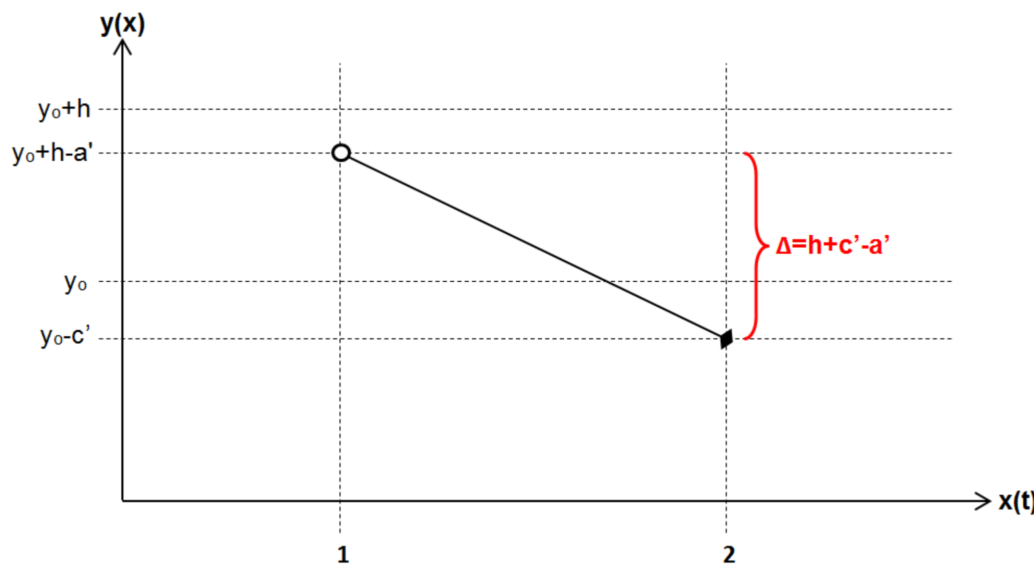
K'_{B3}

$K'_{B3,\,H}$

A wheel flat generates a potential energy for the tributary mass of the wheel

- A part of this energy imparts onto the track-rolling stock equivalent stiffness system and temporarily stores as the potential energy of this equivalent stiffness system.
- As a results of this energy transfer, the dynamic impact force F_i of the wheel differs from the static force of the wheel F_s in relation to the train speed, length of wheel flat, wheel radius and system stiffness.



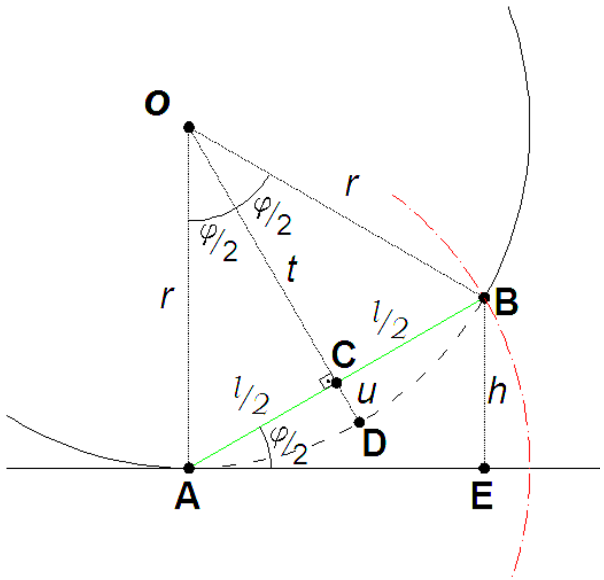


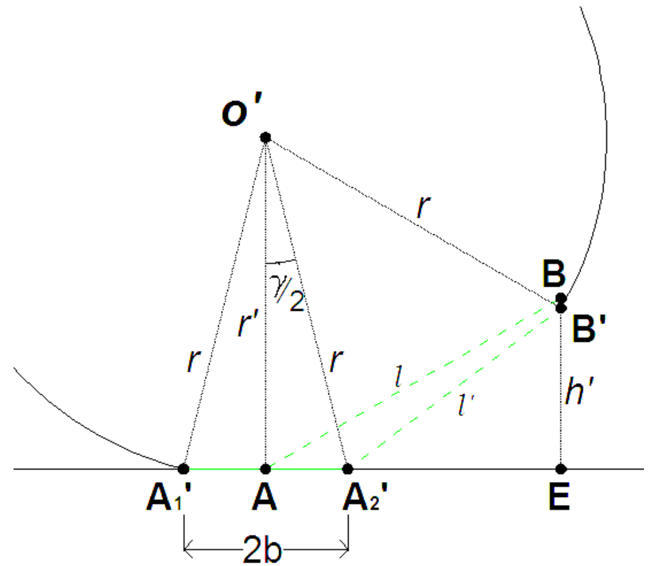
$$\mathrm{m.g.}(\mathrm{h}+\mathrm{c}'-\mathrm{a}')-f.\mathrm{m.g.h}=\frac{1}{2}\mathrm{k}_{eq}(\mathrm{a}'+\mathrm{c}')(\mathrm{c}'-\mathrm{a}')$$

$$f=1-\frac{\mathrm{t_{fall}}}{\mathrm{t_{spin}}}$$

Bezgin – Kolukırık Equations

- An explicit analytical method to estimate the peak forces due to wheel flats.





$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

$$K'_{B3,H} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v.\left(\frac{h'}{h}\right)}{a'.\varphi.\sqrt{r.g}}}$$

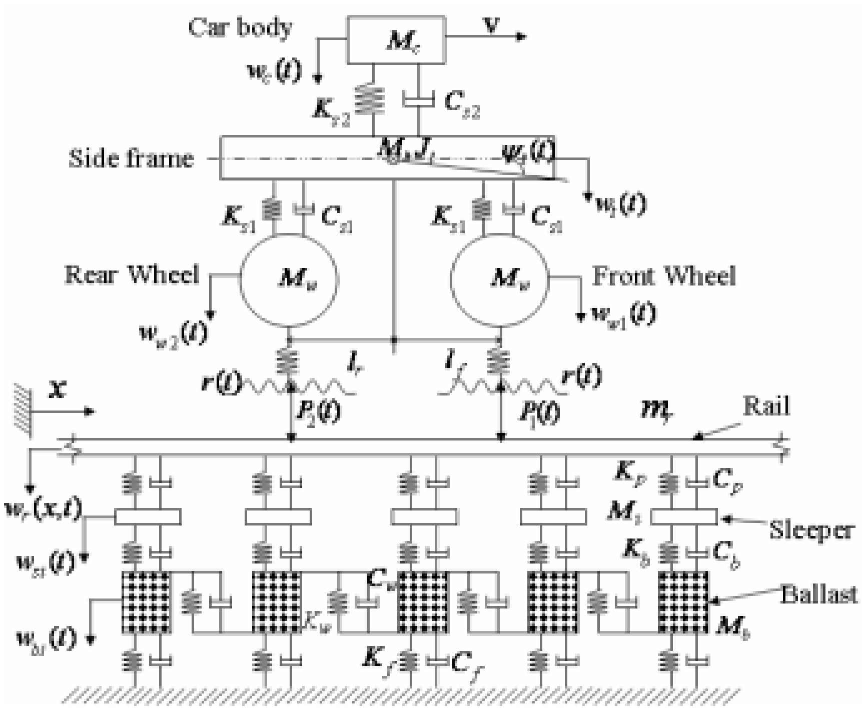
- v is the translational train speed.
- a' is the deflection of the equivalent system stiffness.

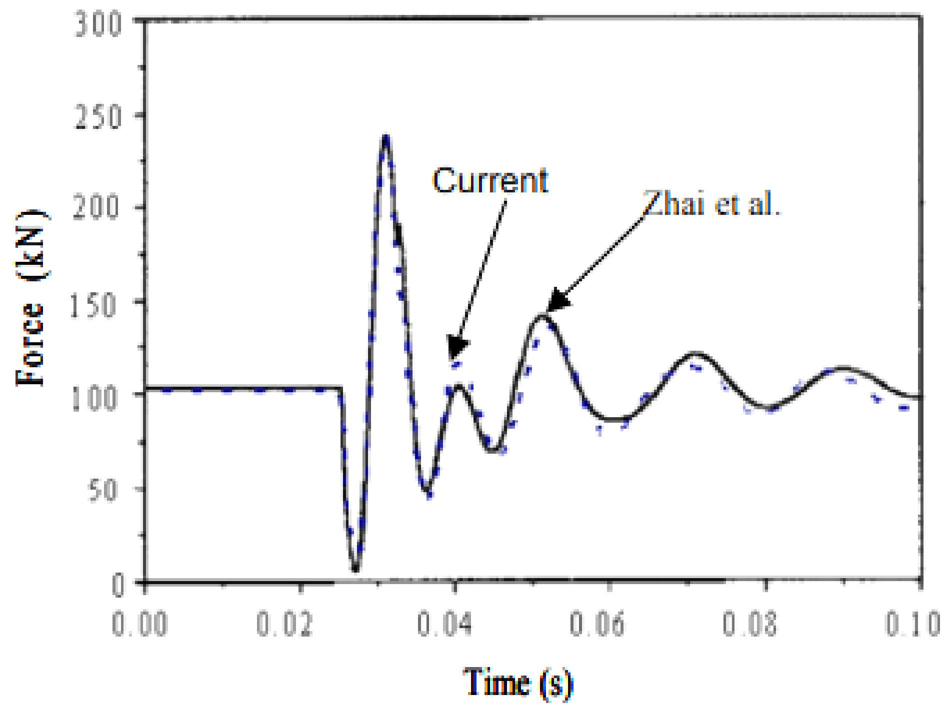
$$\varphi = 2 * \arcsin\frac{l}{D}$$

Numerical analysis for the effects of wheel flats

Uzzal, A. R., Ahmed, W., Rakheja, S. Dynamic Analysis of Railway Vehicle-Track Interactions due to Wheel Flat with a Pitch-Plane Vehicle Model. Journal of Mechanical Engineering. Vol. ME39, No.2, December 2008.

Zhai, W.M., Cai, C.B., Wang, Q., Lu, Z.W., Wu, X.S. Dynamic effects of vehicles on tracks in the case of raising train speed. Proceedings of the Institution of Mechanical Engineers, Part F, v 215, p.125-135, 2001.

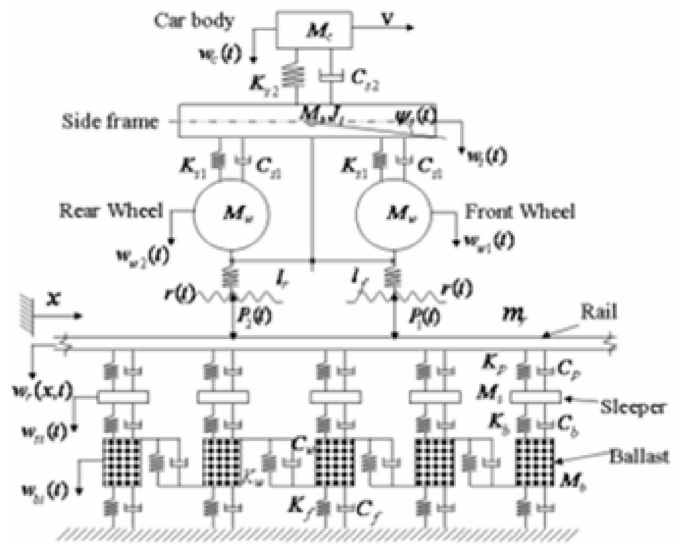




Comparison of estimates

5. First comparison study

- Uzzal, A. R., Ahmed, W., Rakheja, S. *Dynamic Analysis of Railway Vehicle-Track Interactions due to Wheel Flat with a Pitch-Plane Vehicle Model.* Journal of Mechanical Engineering. Vol. ME39, No.2, December 2008.
- Zhai, W.M., Cai, C.B., Wang, Q., Lu, Z.W., Wu, X.S. *Dynamic effects of vehicles on tracks in the case of raising train speed.* Proceedings of the Institution of Mechanical Engineers, Part F, v 215, p.125-135, 2001.



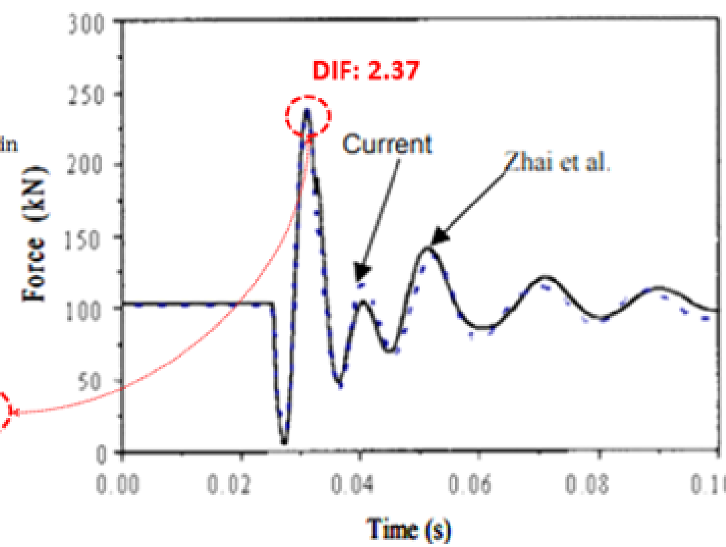
- Authors of the first paper developed a two dimensional track model that employs the Rayleigh-Ritz method to analyze the vehicle-track system.
- Dynamic coupled system of the car supported on a bogie with suspension elements on an Euler-Bernoulli beam track on ballasted track.
- The wheel diameter is **D=840 mm** (33 in) and the train speed is **v=27 km/h** (16.8 mph). The static wheel force is **F_s=103.3 kN** (23.2 kips).

$$\frac{1}{k_{eq}} = \frac{1}{788} + \frac{1}{6.1} + \frac{1}{1377} + \frac{1}{100} \rightarrow k_{eq} = 5.7\frac{\text{kN}}{\text{mm}} = 32.5\frac{\text{kip}}{\text{in}} \qquad a = \frac{F_s}{k_{track}} = \frac{103.2\text{ kN}}{100\frac{\text{kN}}{\text{mm}}} = 1\text{ mm} = 0.04\text{ in}$$

$$\varphi = 2 * \arcsin\frac{l/_2}{r} = 2 * \arcsin\frac{52.8/_2}{420} = 7.2\text{ degrees}=0.126\text{ radians} \qquad a' = \frac{F_s}{k_{eq}} = \frac{103.2\text{ kN}}{5.7\text{ kN/mm}} = 18.1\text{ mm} = 0.7\text{ in}$$

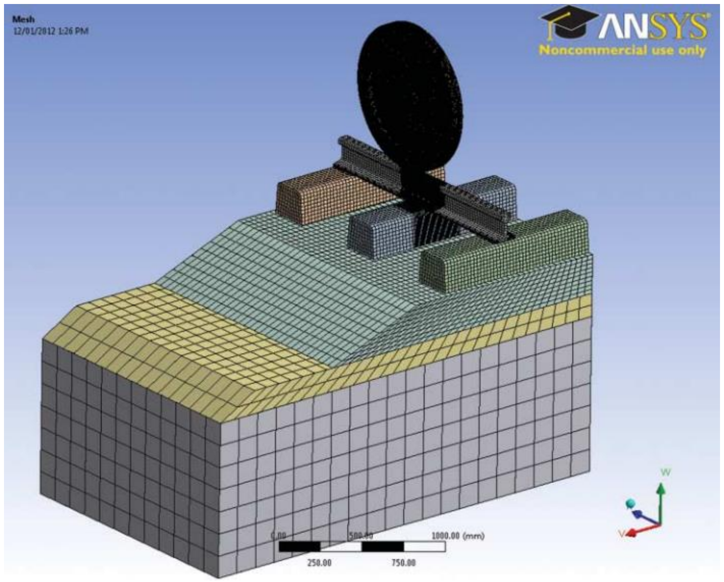
$$K_{B3} = 1 + 4.\sin\frac{\varphi}{2}\sqrt{\frac{\sqrt{r}.v.\sin\frac{\varphi}{2}}{a.\varphi.\sqrt{g}}} = 1 + 4 * \sin\frac{7.2}{2}\sqrt{\frac{\sqrt{460} * \frac{27*1000}{3.6} * \sin\frac{7.2}{2}}{1 * 0.126 * \sqrt{9810}}} = 8.15$$

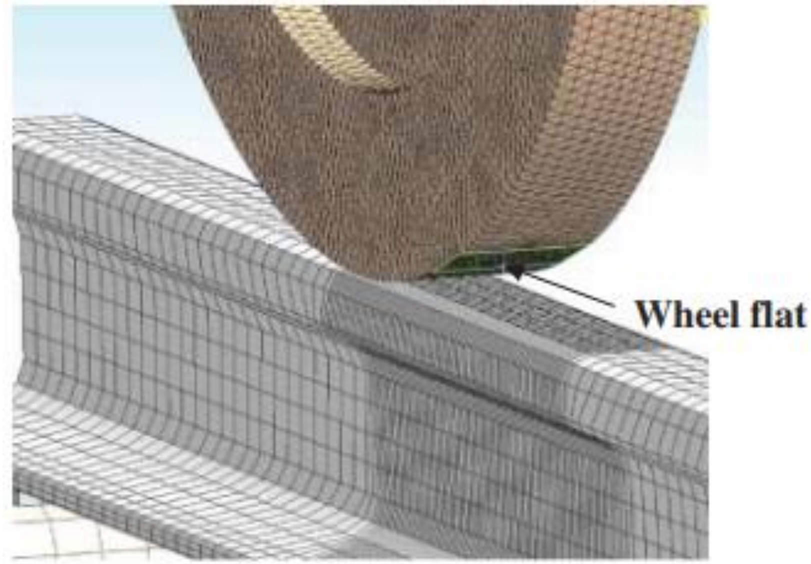
$$K'_{B3} = 1 + 4.\sin\frac{\varphi}{2}\sqrt{\frac{\sqrt{r}.v.\sin\frac{\varphi}{2}}{a'.\varphi.\sqrt{g}}} = 1 + 4 * \sin\frac{7.2}{2}\sqrt{\frac{\sqrt{460} * \frac{27*1000}{3.6} * \sin\frac{7.2}{2}}{18.1 * 0.126 * \sqrt{9810}}} = 2.68$$

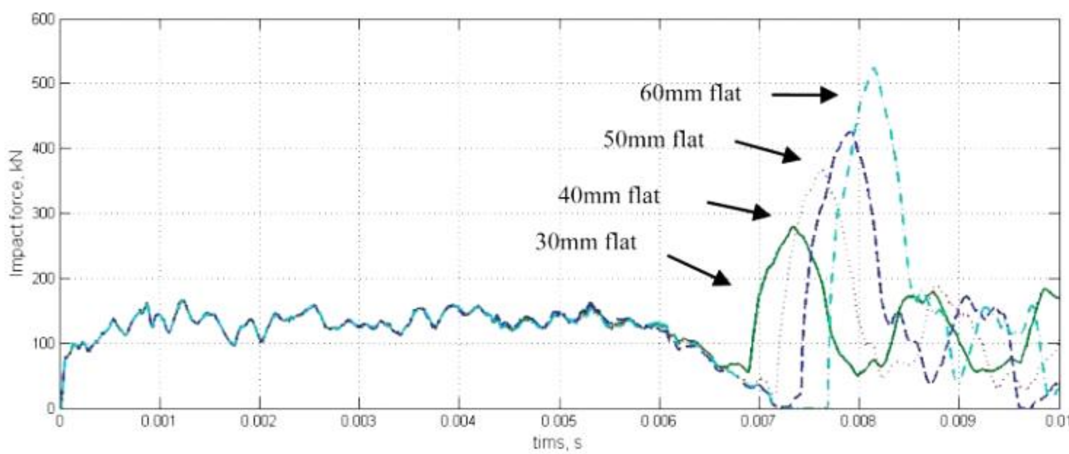


Numerical analysis for the effects of wheel flats

Bjan, J., Gu, Y., Murray, H.W. A dynamic wheel-rail impact analysis of railway track under wheel flat by finite element analysis. Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility. DOI: 10.1080/00423114.2013.774031. March 2013.







Comparison of estimates

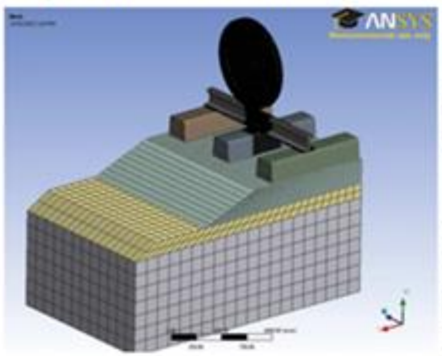
6. Second verification study

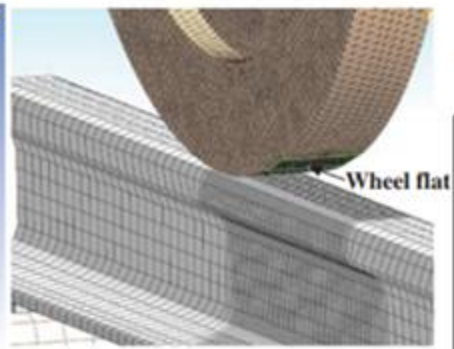
- Bjan, J., Gu, Y., Murray, H.W. *A dynamic wheel-rail impact analysis of railway track under wheel flat by finite element analysis*. Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility. DOI: 10.1080/00423114.2013.774031. March 2013.
- Zilli, L., Zhao, X., Esveld, C., Dollevoet, R., Molodova, M. *Investigation into the causes of squats-correlation analysis and numerical modelling*. Wear. 265, p.1349-1355. 2008.
- Wheel spring stiffness used in this study is k_w=1.15 MN/m (6.6 kip/in), the rail pad stiffness is k_p=1300 MN/m (7,413 kip/in), the ballast stiffness per rail seat is k_b=45 MN/m (257 kip/in). This study excludes Hertzian contact stiffness.
- The rail is an Australian standard type AS-60 rail. The wheel diameter is 915 mm (36 in) and the center-to-center sleeper spacing is s=68.5 cm (2.25 ft). The authors conduct an array of analysis for train speed v=72 km/h (44.7 mph) and a static wheel force of F_s=128 kN (29 kips)

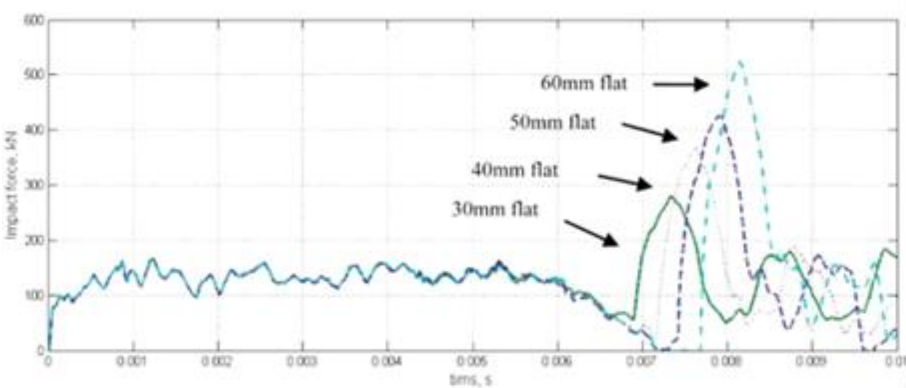
$$\frac{1}{k_{eq}} = \frac{1}{k_{track}} + \frac{1}{k_w} = \frac{1}{100} + \frac{1}{1.15} \rightarrow k_{eq} = 1.14\ \frac{MN}{m} = 6.5\ \text{kip/in}$$

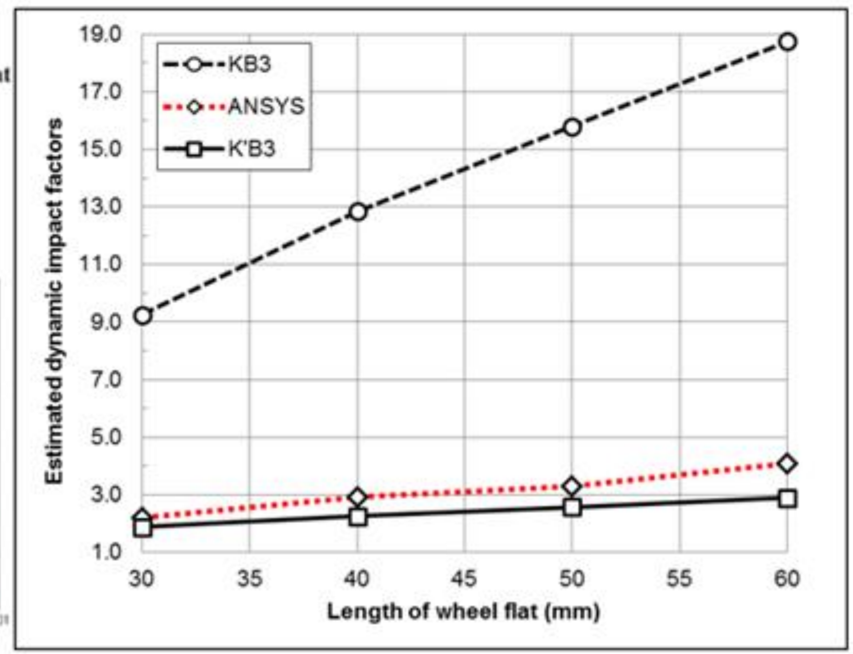
$$a = \frac{F_s}{k} = \frac{127.9\ \text{kN}}{100\ \text{N/mm}} = 1.28\ \text{mm} = 0.05\ \text{in}$$

$$a' = \frac{F_s}{k_{eq}} = \frac{127.9\ \text{kN}}{1.14\ \text{N/mm}} = 112.2\text{mm} = 4.4\ \text{in}$$





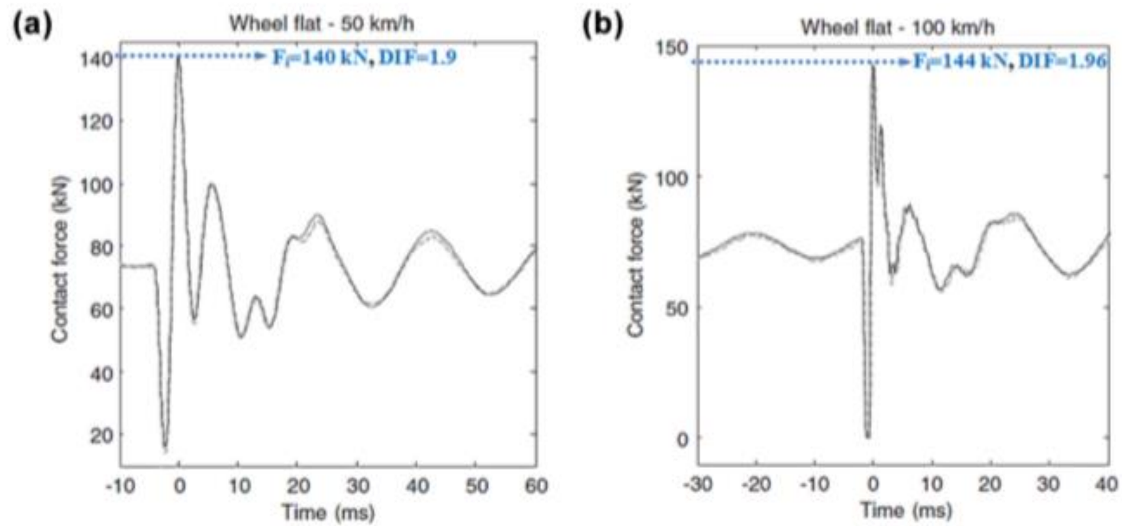




Comparison of estimates

Table 2. Geometric and Mechanical Track and Rolling Stock Parameters Extracted from Baeza et al. and Parameters Calculated (16)

Sleeper spacing (m)	0.65
F_s (kN)	73.6
I_{rail} (m^4)	3.05E–05
E_{rail} (N/m^2)	2.10E+11
u_{track} (N/m^2)	6.79E+07
Stiffness of a pad (N/m)	1.50E+08
Wheel diameter (mm)	1000
Wheel flat length (mm)	92.7 mm
First speed for train (km/h)	50
Second speed for train (km/h)	100
u_{pad} (N/m^2)	2.31E+08
$u_{track+pad} = 1/([1/u_{track}] + [1/u_{pad}])$ (N/m^2)	5.25E+07
L (m)	8.36E–01
$k_{track+pad}$ (kN/mm)	87.7
k_w (kN/mm)	1.0
k_b (kN/mm)	0.35
$k_{eq} = 1/([1/k_{track+pad}] + [1/k_w] + [1/k_b])$ (kN/mm)	0.26



$$K'_{B3,\, v\,=\,50} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

$$= 1 + 2.\sin\frac{10.64}{2}\sqrt{\frac{2 * 0.0927 * 13.89}{0.285 * 0.1856 * \sqrt{0.5 * 9.81}}} = 1.87$$

$$K'_{B3,\, v\,=\,100} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

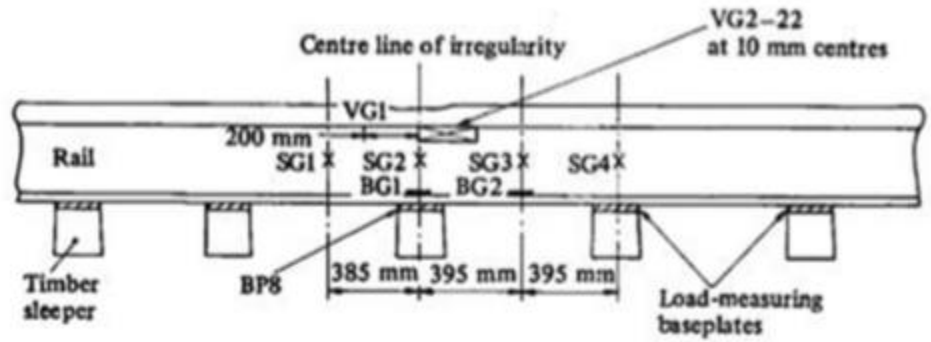
$$= 1 + 2.\sin\frac{10.64}{2}\sqrt{\frac{2 * 0.0927 * 27.78}{0.285 * 0.1856 * \sqrt{0.5 * 9.81}}} = 2.23$$

Baeza, L., A. Roda, and J. C. O. Nielsen. Railway Vehicle/ Track Interaction Analysis using a Modal Substructuring Approach. Journal of Sound and Vibration, Vol. 293, 2006, pp. 112–124.

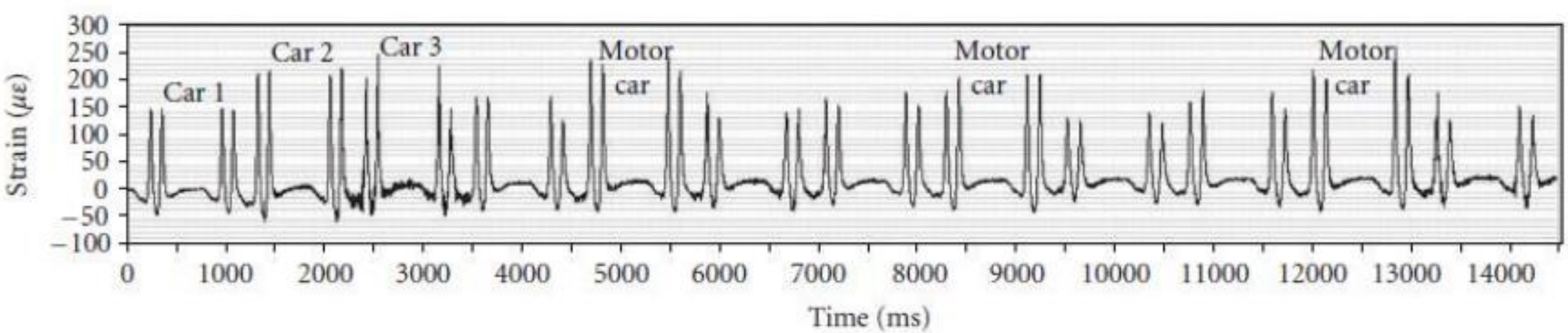
Wheel impact load detectors or instrumented special tracks

http://www.trackiq.com.au/WCM.html

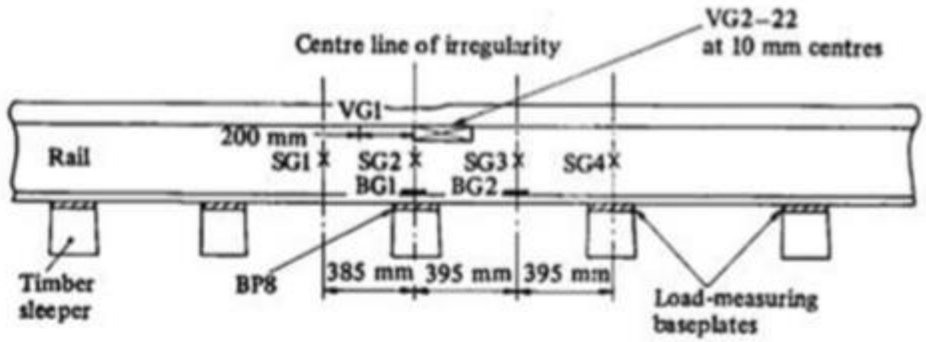
Newton, S. G., and R. A. Clark. An Investigation into the Dynamic Effects on the Track of Wheelflats on Railway Vehicles. Journal of Mechanical Engineering Sciences, Vol. 21, No. 4, 1979, pp. 287–297.



Review Article:
Review on condition monitoring approaches for the detection of railway wheel defects.
Alireza Alemi, Francesco Corman, Gabriel Lodewijks Faculty of Mechanical, Maritime and Material Engineering (3mE), Delft University of Technology, The Netherlands



Comparison of estimates



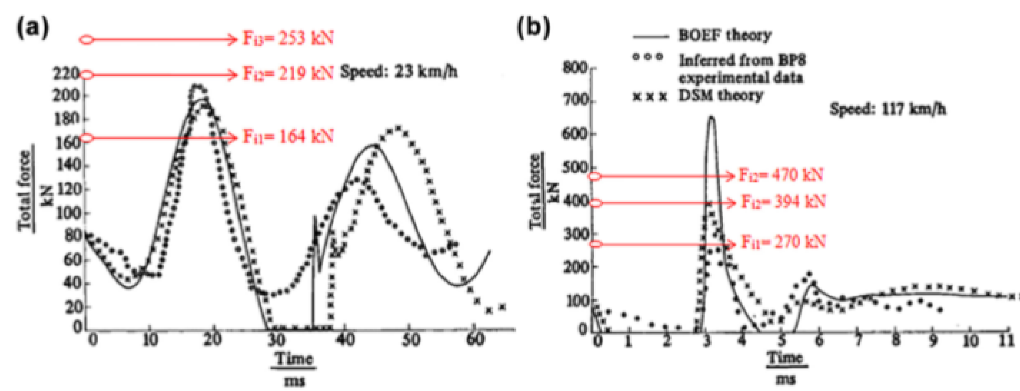


Figure 9. Dynamic impact force estimates and measurements from the paper by Newton and Clark (*15*): (*a*) train speed v = 23 km/h, (*b*) train speed v = 117 km/h.

Note: BOEF = beam on elastic foundation; BP8 = load measuring base plate and plate number; DSM = discrete support model.

Newton, S. G., and R. A. Clark. An Investigation into the Dynamic Effects on the Track of Wheel flats on Railway Vehicles. Journal of Mechanical Engineering Sciences, Vol. 21, No. 4, 1979, pp. 287–297.

An improved estimate of system deflection a’ improves the estimate for K'_{B3}

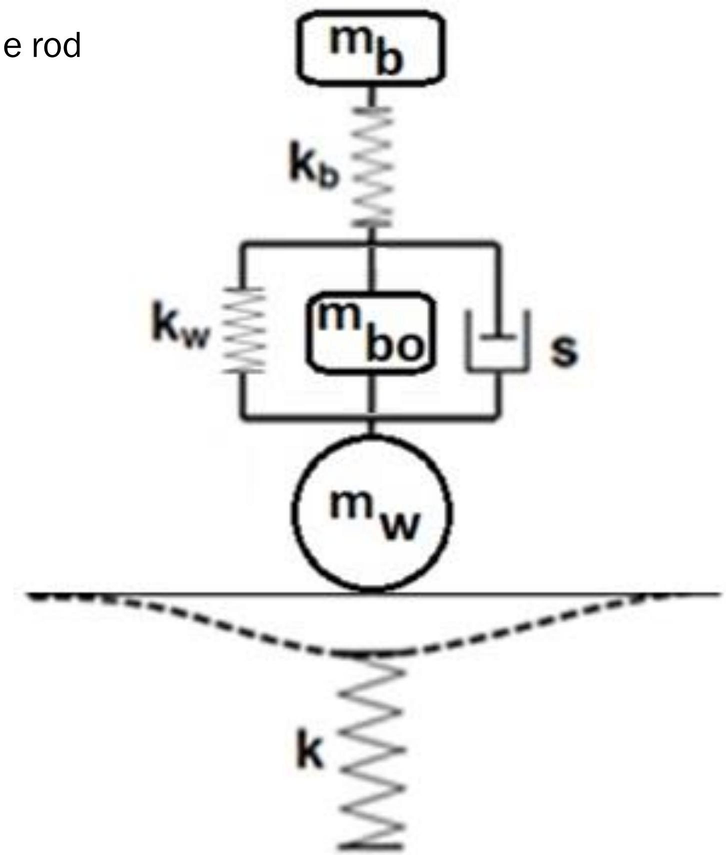
$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

Constituents of the tributary wheel mass and system stiffness

- Components of the tributary wheel mass:

  1. m_w = Mass of the wheel, mass of brake disk per wheel, mass of axle rod per wheel
  2. m_{bo} = Tributary mass of the bogie per wheel
  3. m_b = Tributary mass of the body per wheel

  $$m_T = m_w + m_{bo} + m_b$$



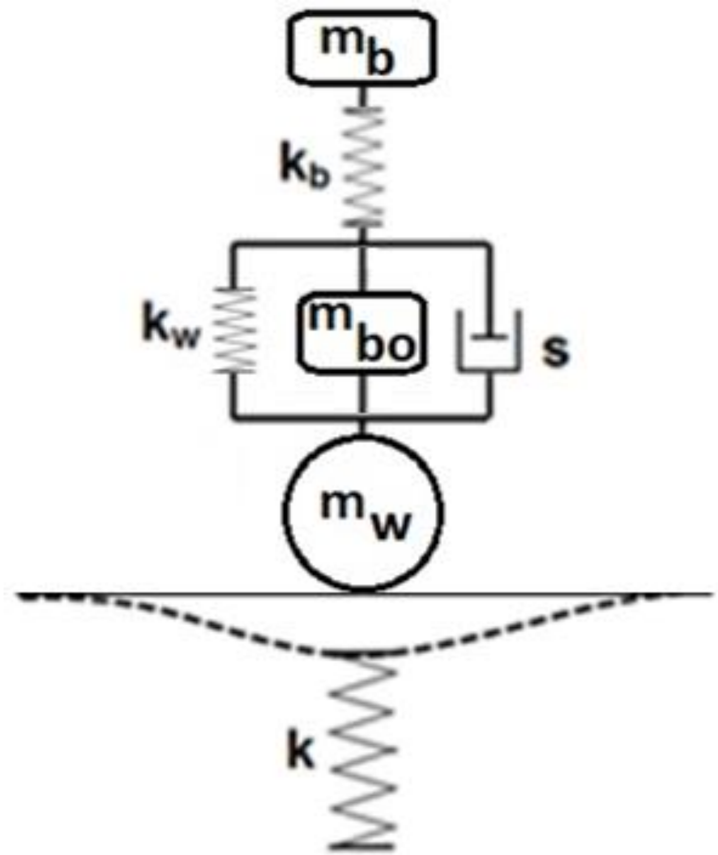
- Stiffness components of the system:

  1. k = Stiffness of the track per wheel
  2. k_w = Primary wheel spring
  3. k_b = Secondary body spring

Stiffness elements that support the tributary mass components

- Equivalent stiffness value supporting the mass components:

1. k : Supporting the wheel/break disks and the axle
2. k_w and $k = \frac{1}{\left(\frac{1}{k_w}+\frac{1}{k}\right)}$: Supporting the bogie
3. $k_T = \frac{1}{\left(\frac{1}{k_b}+\frac{1}{k_w}+\frac{1}{k}\right)}$: Supporting the body

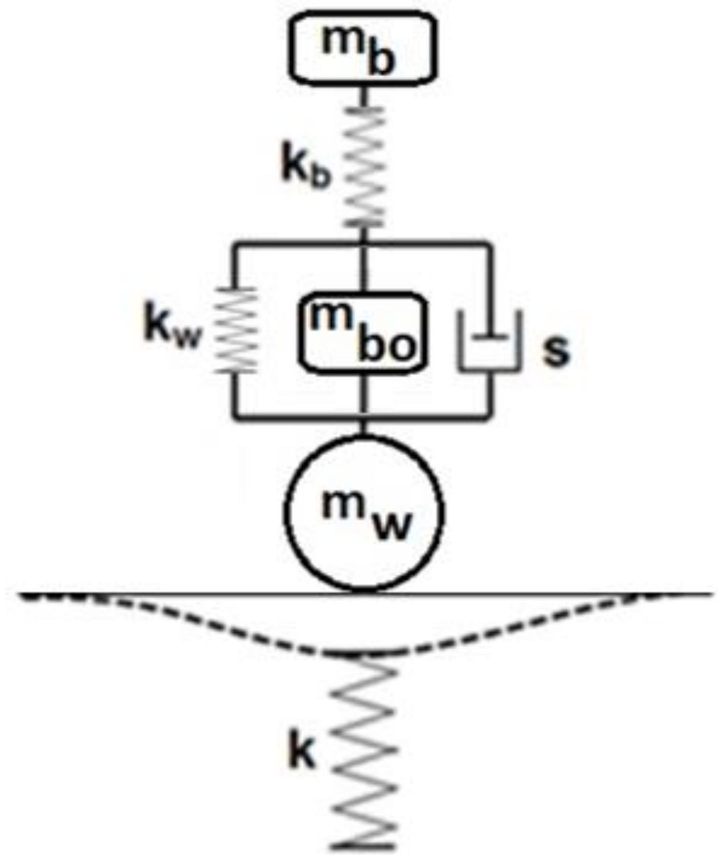


Estimation of the system deflection if mass details are known

- Components of the total static wheel force:

  1. $F_w = m_w .g$ = Weight of the wheel/break disk/half the axle rod
  2. $F_{bo} = m_{bo} .g$ = Weight of the tributary bogie mass
  3. $F_b = m_b .g$ = Weight of the tributary body mass

$$F_s = F_w + F_{bo} + F_b$$



- Components of the total static system deflection:

  1. $a'_w = F_w / k$ = Deflection contributed by the wheel
  2. $a'_{bo} = F_{bo} / k_{w+k}$ = Deflection contributed by the bogie
  3. $a'_b = F_b / k_T$ = Deflection contributed by the body

$$a' = a'_w + a'_{bo} + a'_b$$

$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

Estimation of the system deflection if mass details are unknown

- Total static wheel force: F_s = 85 kN, 125 kN… etc

- Equivalent system stiffness: $\mathbf{k_T} = \frac{1}{\left(\frac{1}{k_b}+\frac{1}{k_w}+\frac{1}{k}\right)}$

$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

- Equivalent system deflection: $a' = F_s / k_T$

- If the primary and secondary stiffness elements were absent, the total tributary mass would be supported by the stiffness of the track only and this would be the stiffest support condition.

K'_{B3} provides a manual way to estimate the peak forces

ESTIMATION OF PEAK DYNAMIC IMPACT FORCE DUE TO A WHEEL FLAT (MASS DIST. UNKNOWN)

$F_s = 90\ kN$

$v = 200\ km/h$

$l = 30\ mm$

$D = 920\ mm$

$k = 60\ kN/mm$

$k_w = 10\ kN/mm$

$k_b = 5\ kN/mm$

$$k_T = \frac{1}{\frac{1}{k_b} + \frac{1}{k_w} + \frac{1}{k}}$$

$$k_T = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{60}}$$

$k_T = 3.16\ kN/mm$

$a' \cong F_s / k_T$

$\therefore a' = 28.48\ mm$

$$K'_{B3} = 1 + 2\sin\frac{\phi}{2}\sqrt{\frac{2.l.v}{a'.\phi.\sqrt{r.g}}}$$

$$\phi = 2.\arcsin\frac{l}{D}$$

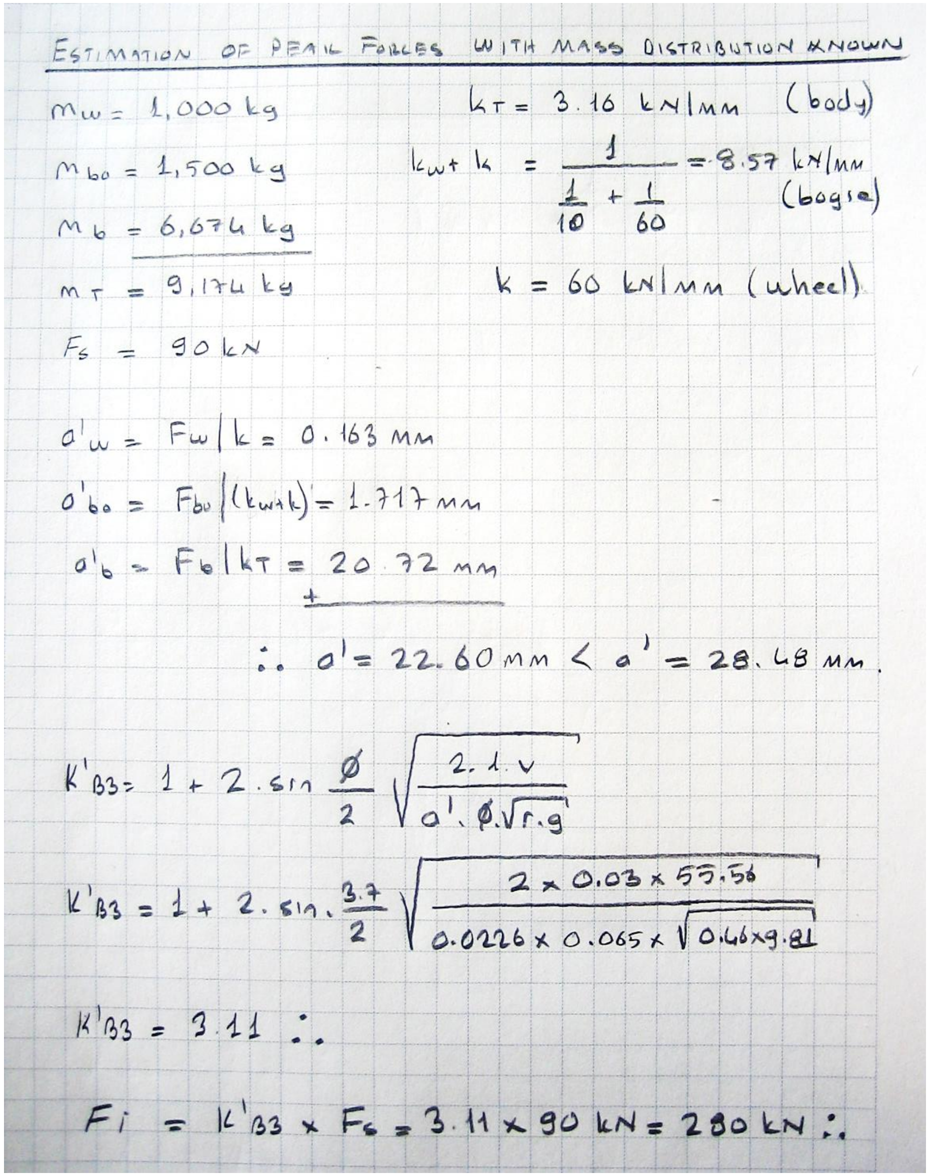
$$\phi = 2.\arcsin\frac{30}{920} = 3.737^\circ = 0.065\ rad$$

$$K'_{B3} = 1 + 2\sin\frac{3.7}{2}\sqrt{\frac{2 \times 0.03 \times 55.56}{0.028 \times 0.065 \times \sqrt{0.46 \times 9.81}}}$$

$K'_{B3} = 2.895\ \therefore$

$F_i = K'_{B3} \times F_s = 260.6\ kN \therefore$

K'_{B3} provides a manual way to estimate the peak forces



ESTIMATION OF PEAK FORCES WITH MASS DISTRIBUTION KNOWN

$m_w = 1{,}000\ kg$ $\qquad k_T = 3.16\ kN/mm$ (body)

$m_{bo} = 1{,}500\ kg$ $\qquad k_w + k = \dfrac{1}{\frac{1}{10} + \frac{1}{60}} = 8.57\ kN/mm$ (bogie)

$m_b = 6{,}674\ kg$

$m_T = 9{,}174\ kg$ $\qquad k = 60\ kN/mm$ (wheel)

$F_s = 90\ kN$

$a'_w = F_w / k = 0.163\ mm$

$a'_{bo} = F_{bo} / (k_w + k) = 1.717\ mm$

$a'_b = F_b / k_T = 20.72\ mm$

+

$\therefore\ a' = 22.60\ mm < a' = 28.48\ mm.$

$$K'_{B3} = 1 + 2 . \sin \frac{\phi}{2} \sqrt{\frac{2 . 1 . v}{a' . \phi . \sqrt{r . g}}}$$

$$K'_{B3} = 1 + 2 . \sin . \frac{3.7}{2} \sqrt{\frac{2 \times 0.03 \times 55.56}{0.0226 \times 0.065 \times \sqrt{0.46 \times 9.81}}}$$

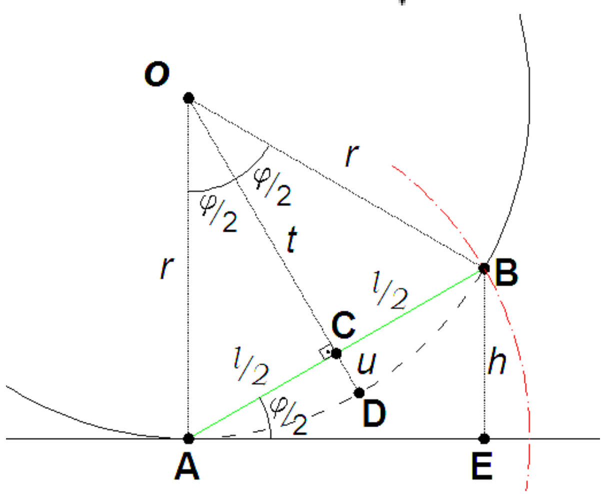
$K'_{B3} = 3.11\ \therefore$

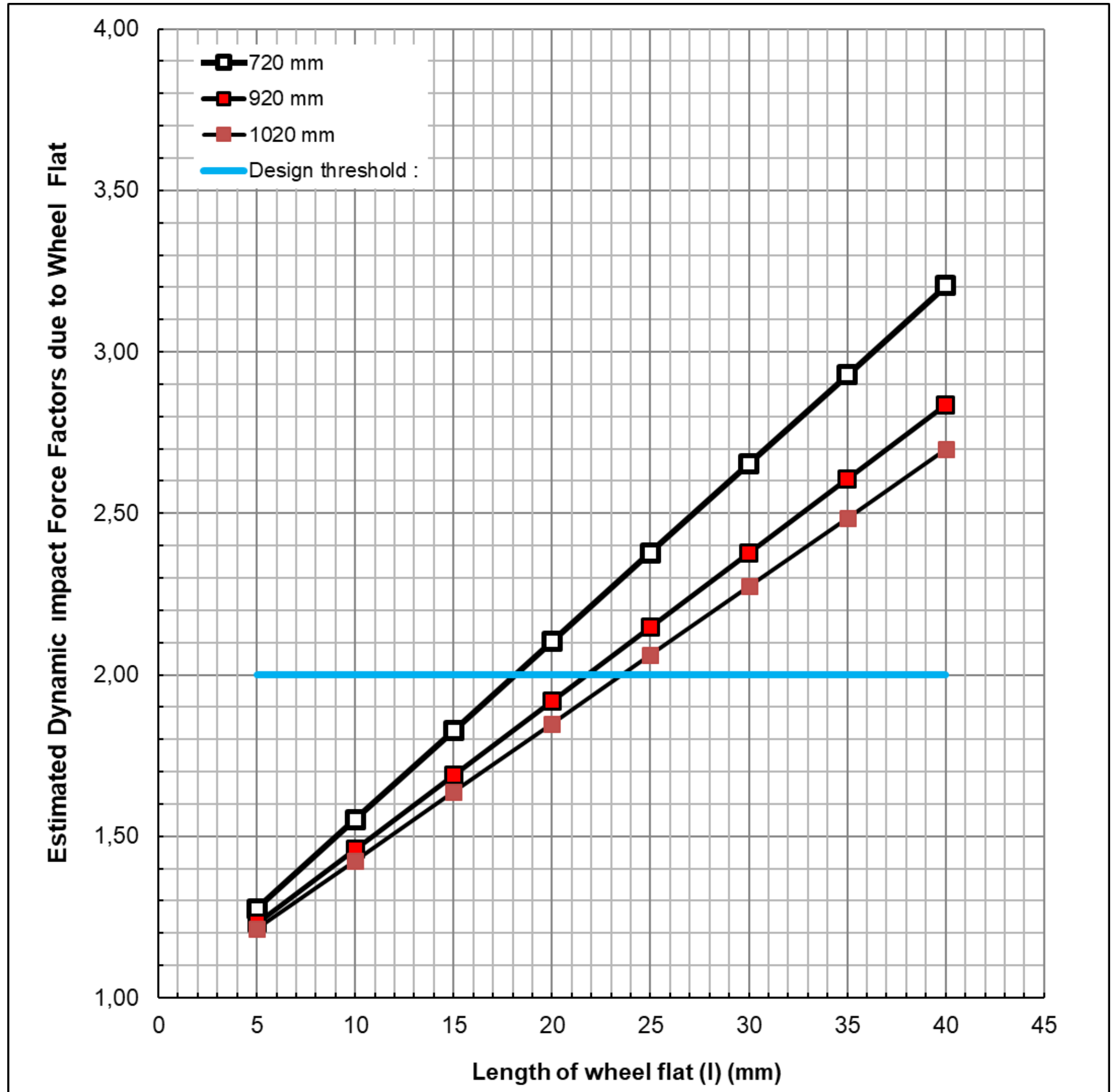
$F_i = K'_{B3} \times F_s = 3.11 \times 90\ kN = 280\ kN\ \therefore$

Increasing dynamic impact forces with increasing wheel curvature
Resultant static wheel force known, mass distribution unknown

- $v = 100$ km/h
- $k = 60$ kN/mm
- $k_w = 10$ kN/mm
- $k_b = 5$ kN/mm
- $m_T = 7{,}825$ kg
- $F_s = 76.8$ kN

$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

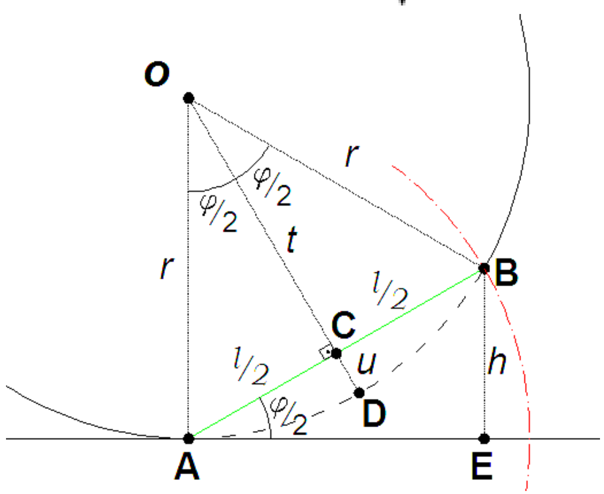


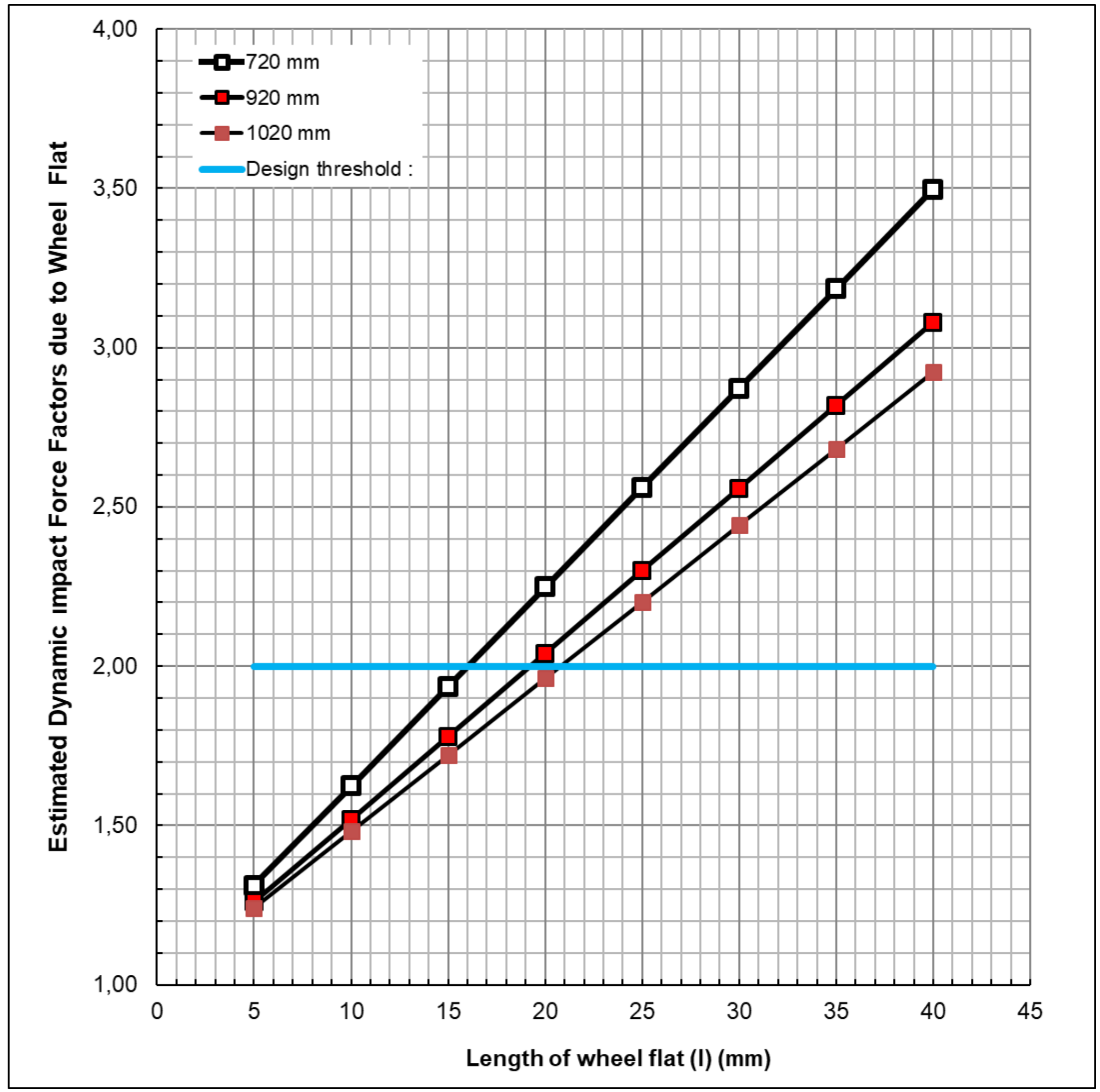


Increasing dynamic impact forces with increasing wheel curvature
Mass distribution known

- v = 100 km/h
- k = 60 kN/mm
- k_w = 10 kN/mm
- k_b = 5 kN/mm
- m_w=900 kg
- m_{bo}=1,300 kg
- m_b=5,625 kg
- F_s = 76.8 kN

$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

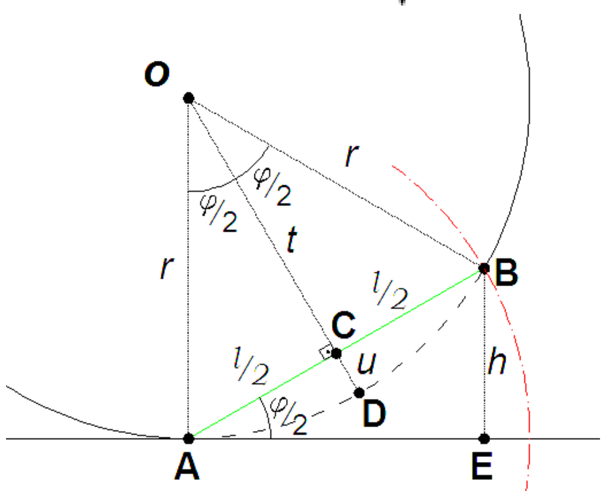


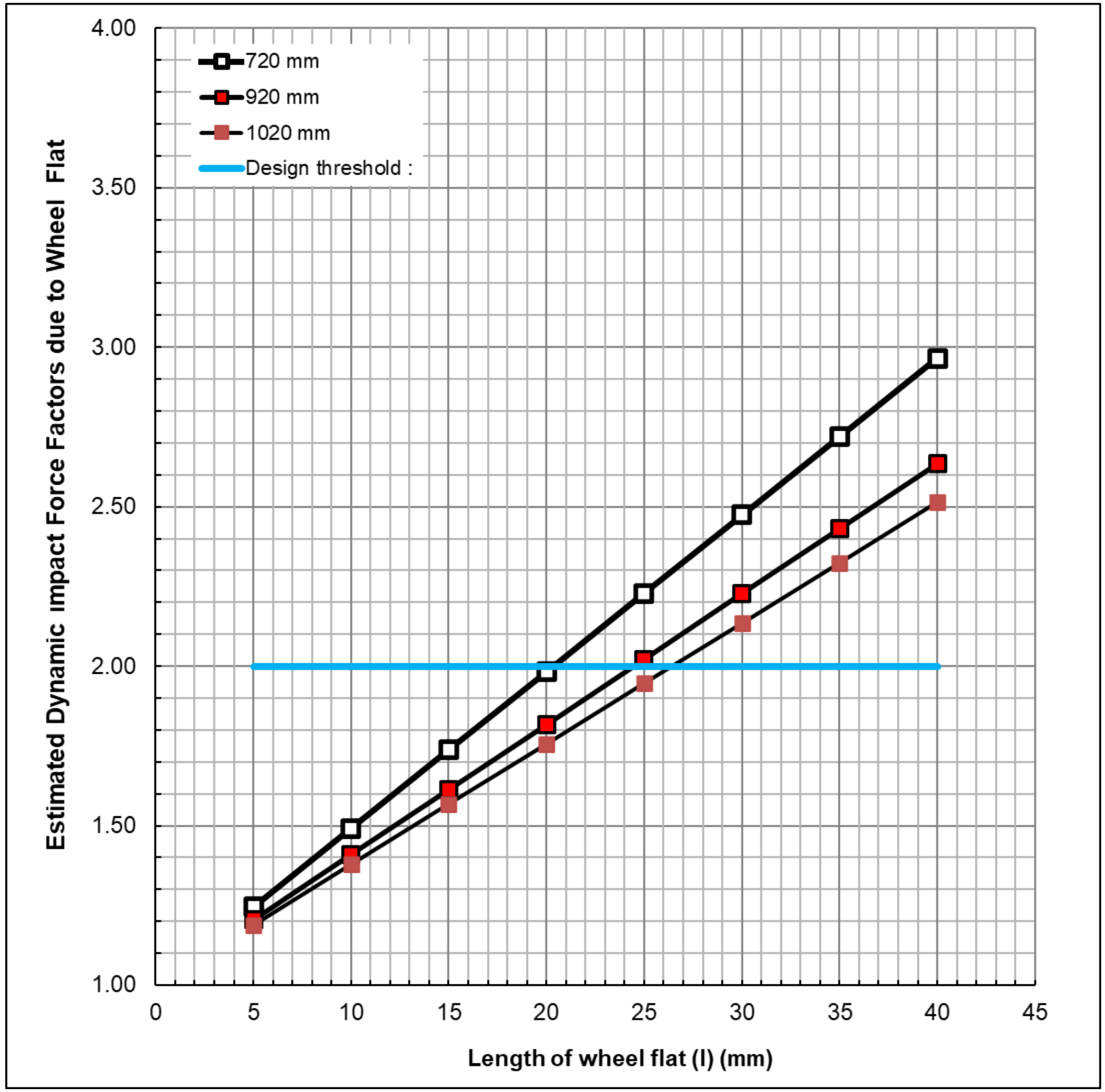


Decreasing dynamic impact forces with increasing static wheel force. Mass distribution known

- v = 100 km/h
- k = 60 kN/mm
- k_w = 10 kN/mm
- k_b = 5 kN/mm
- m_w=900 kg
- m_{bo}=1,300 kg
- m_b=9,375 kg
- F_s = 113.6 kN

$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

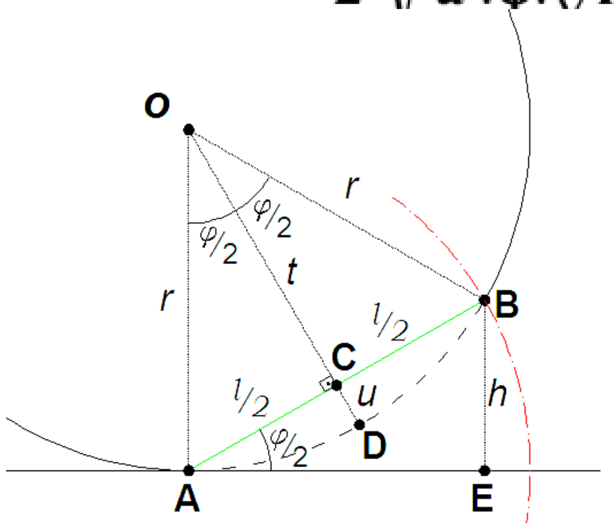


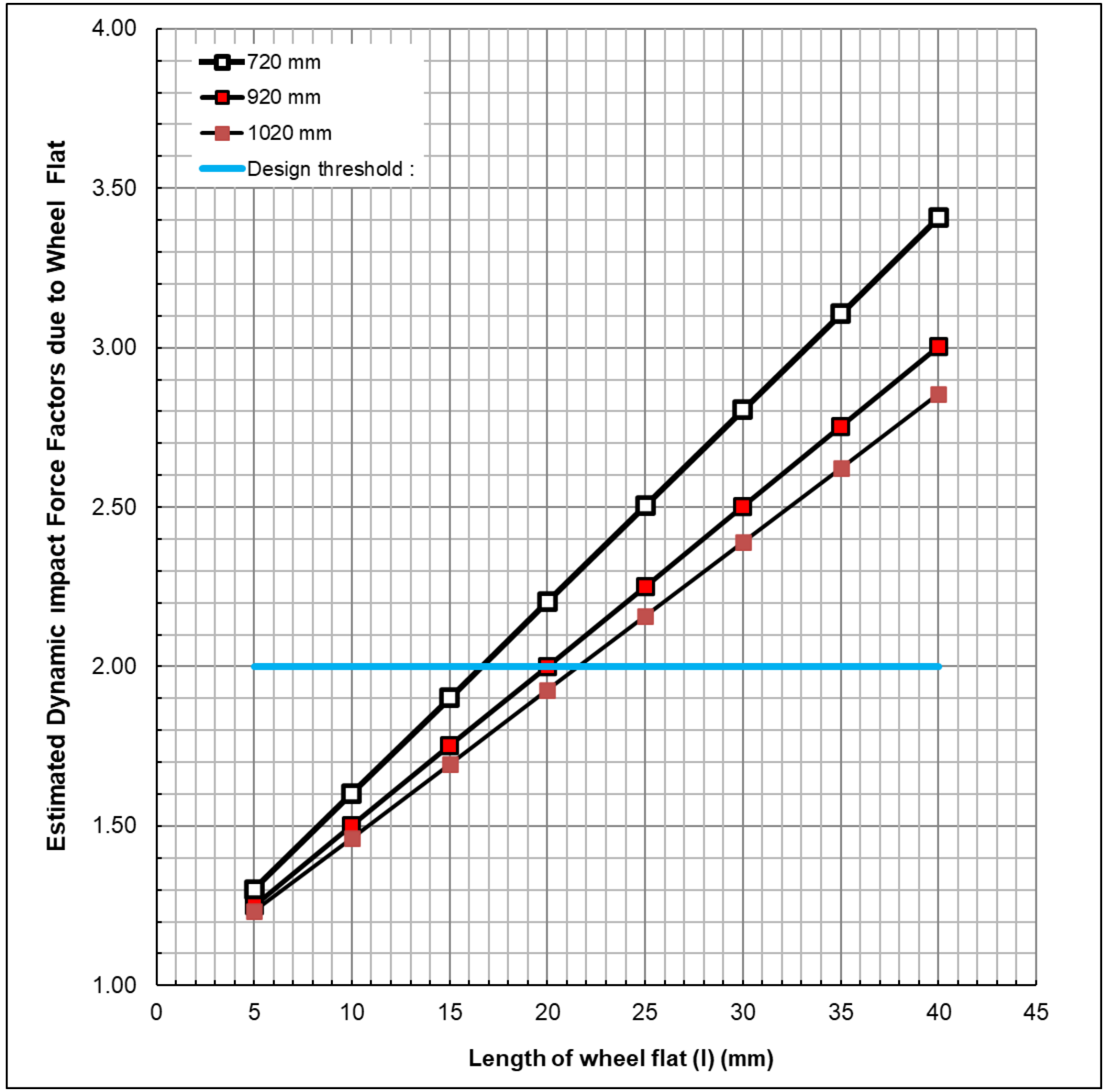


Increasing dynamic impact forces with increasing speed. Mass distribution known

- $v = 150$ km/h
- $k = 60$ kN/mm
- $k_w = 10$ kN/mm
- $k_b = 5$ kN/mm
- $m_w = 900$ kg
- $m_{bo} = 1{,}300$ kg
- $m_b = 9{,}375$ kg
- $F_s = 113.6$ kN

$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

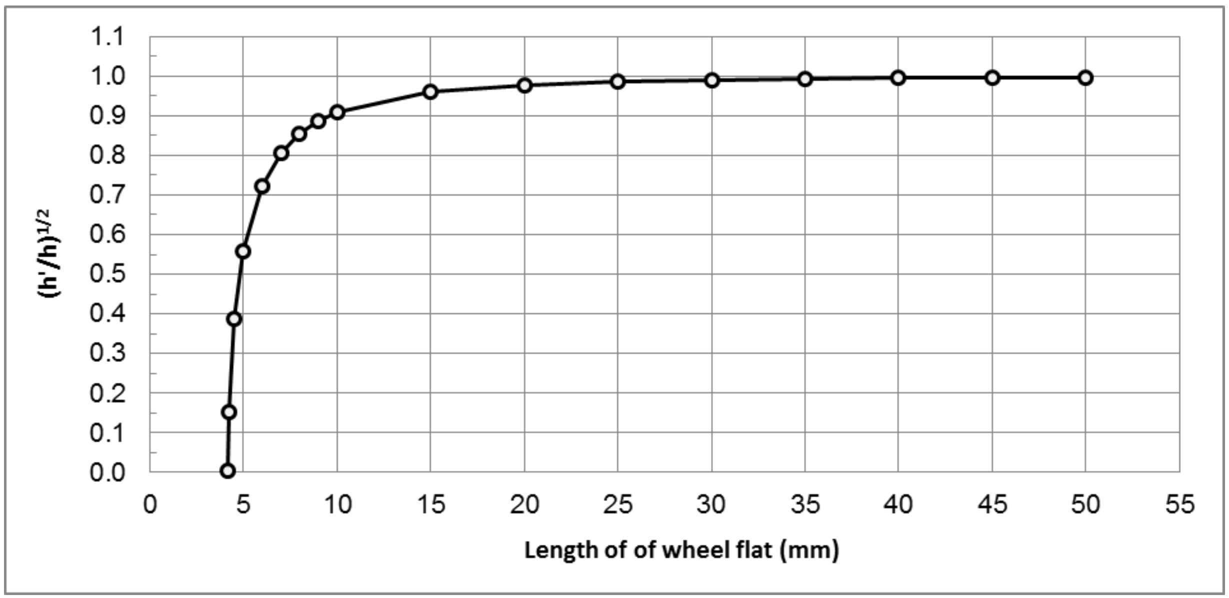


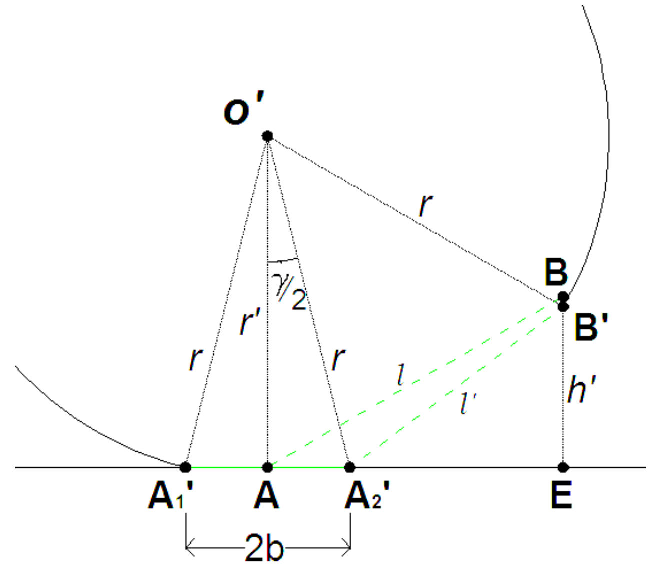


$K'_{B3\text{-}H}$ that considers the effect of Hertzian contact deformation on the dynamic impact due to a wheel flat

$$K'_{B3,H} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v.\left(\frac{h'}{h}\right)}{a'.\varphi.\sqrt{r.g}}}$$

- Use of this equation requires a Hertizan contact deformation analysis and an estimate for 2b.





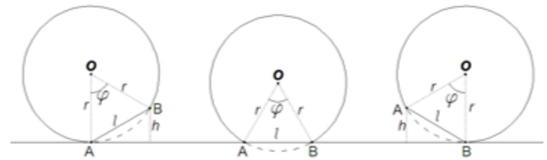
$K'_{B3\text{-}H}$ that considers the effect of Hertzian contact deformation on the dynamic impact due to a wheel flat

ALLTRACK® V2 — PROFILE VARIATION / STIFFNESS TRANSITION / **WHEEL FLAT**

- THIS PART ESTIMATES DYNAMIC IMPACT FORCE FACTORS DUE TO **WHEEL FLATS**
- EQUATIONS USED: K'_{B3} - $K'_{B3,H}$

*Please read the **Welcome to ALLTRACK** tab first and then proceed to enter the input parameters in turquoise.*

1	Track stiffness per wheel (k) (kN/mm) =	60.0
2	Primary wheel spring stiffness (k_w) (kN/mm) =	10.0
3	Secondary bogie spring stiffness (k_b) (kN/mm) =	4.3
4	Hertzian contact stiffness (k_H) (kN/mm) =	20,000
5	Total system stiffness:1 (k_T) (kN/mm) =	2.8
6	Do you have the mass distribution (Type "yes" or "no") ? :	yes
7	Mass of axle with two wheels and break disks (kg) =	1,800
8	Mass of bogie (kg) =	5,200
9	Mass of body (kg) =	45,000
10	Number of axles per bogie =	2
11	Number of bogies per body =	2
12	Static vertical wheel force on tangent (F_s) (kN) =	76.8
13	Static track deflection (a) (mm) =	1.28
14	Static system deflection (a') (mm) =	21.06
15	Wheel diameter (mm) =	1020
16	Speed of train (v) (km/h) =	100
	(m/s) =	27.8
17	Hertzian contact width at interface (2b) (mm) =	10

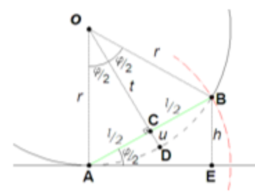


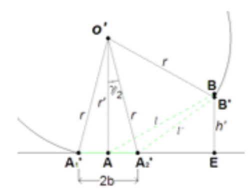
$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}}$$

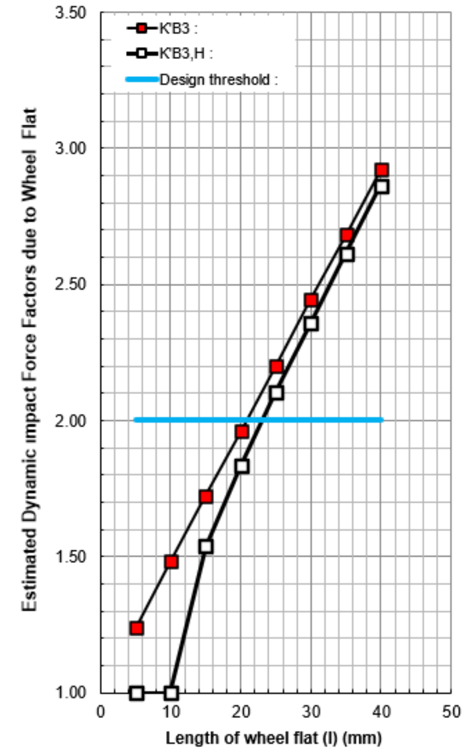
$$K'_{B3,H} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v.\left(\frac{h'}{h}\right)}{a'.\varphi.\sqrt{r.g}}}$$

$$f = 1 - \frac{t_{fall}}{t_{spin}} = 1 - \frac{2.\sin\frac{\varphi}{2}\sqrt{\frac{r}{g}}}{\varphi.r/_{2.v}} = 1 - \frac{4.v.\sin\frac{\varphi}{2}}{\varphi.\sqrt{r.g}} \qquad l = 2r.\sin\frac{\varphi}{2} \qquad h = l.\sin\frac{\varphi}{2}$$

$$u = r\left(1 - \cos\frac{\varphi}{2}\right) \qquad \gamma = 2.\arcsin\frac{b}{r} \qquad u' = r\left(1 - \cos\frac{\gamma}{2}\right) \qquad h' = h - u'$$





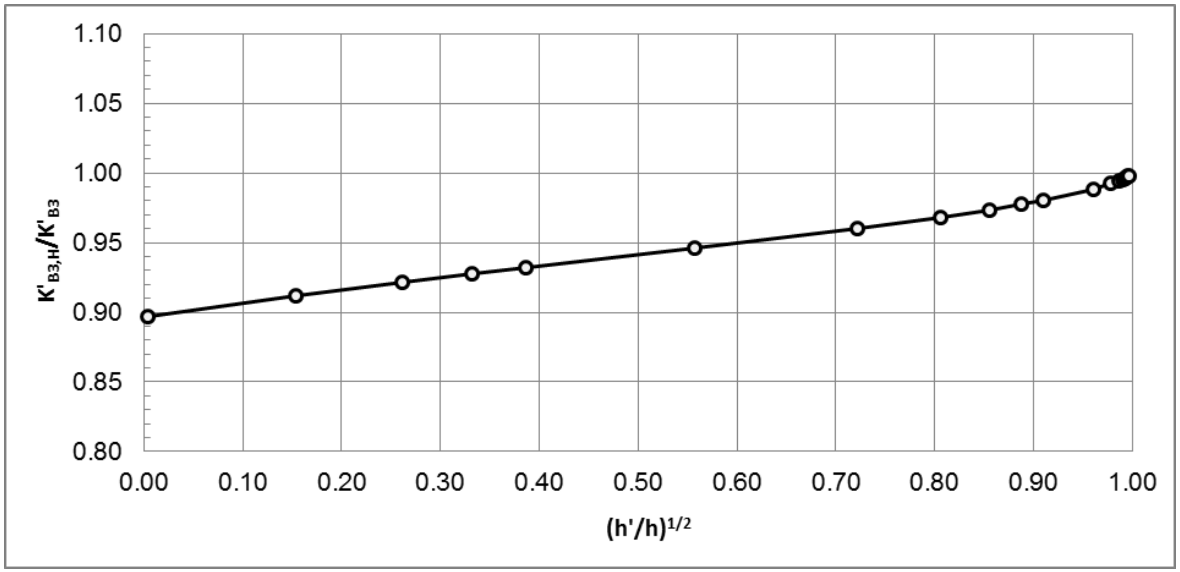


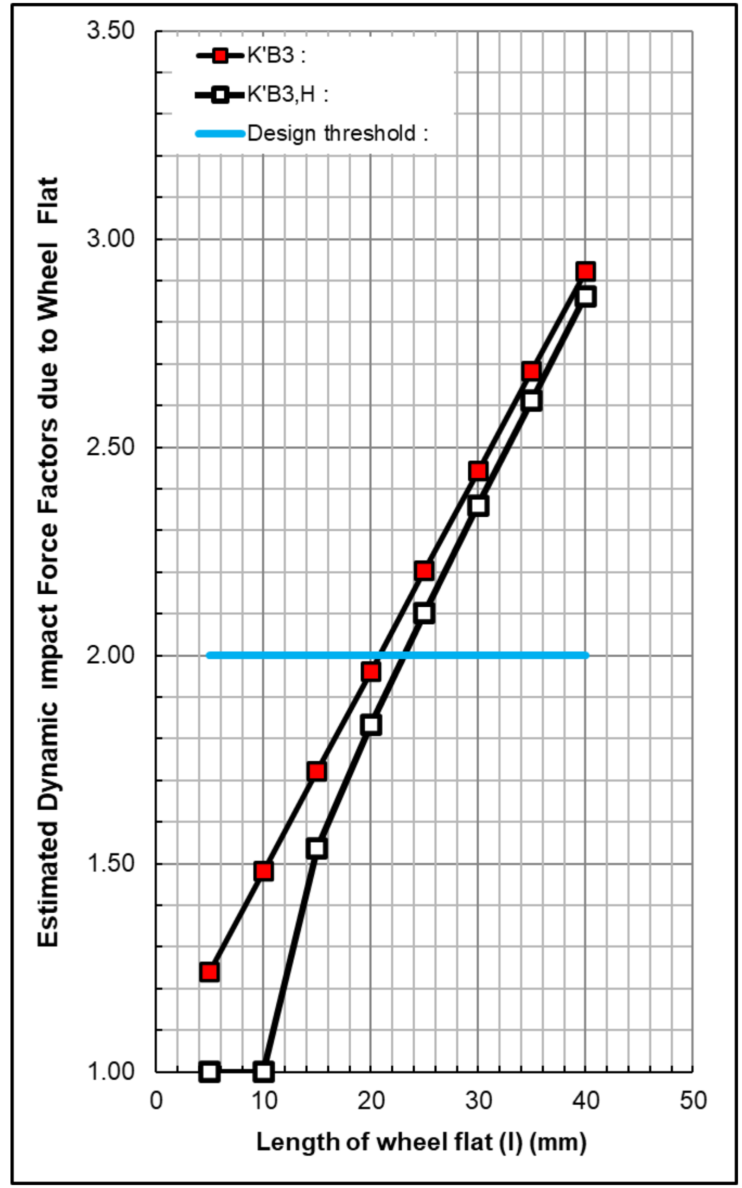
18	Length of wheel flat (l) (mm) =	5	10	15	20	25	30	35	40
19	Time to spin around A and hit rail at B, t_{spin} (s) =	0.00009	0.00018	0.00027	0.00036	0.00045	0.00054	0.00063	0.00072
20	Wheel flat chord angle (φ) (rad) =	0.010	0.020	0.029	0.039	0.049	0.059	0.069	0.078
21	Depth of wheel flat (u) (mm) =	0.006	0.025	0.055	0.098	0.153	0.221	0.300	0.392
22	Wheel flat step height (h) (mm) =	0.025	0.098	0.221	0.392	0.613	0.882	1.201	1.569
23	Hertzian deformed step height (h') (mm) =	0.000	0.000	0.123	0.294	0.515	0.784	1.103	1.471
24	h/a' =	0.001	0.005	0.010	0.019	0.029	0.042	0.057	0.074
25	h'/a' =	0.000	0.000	0.006	0.014	0.024	0.037	0.052	0.070
26	K'B3 :	1.24	1.48	1.72	1.96	2.20	2.44	2.68	2.92
27	K'B3,H :	1.00	1.00	1.54	1.83	2.10	2.36	2.61	2.86
28	**Dynamic impact force exerted on track: F_i (kN) =**	95.2	113.7	132.1	150.6	169.0	187.5	206.0	224.4
29	**Dynamic impact force exerted on track: $F_{i,H}$ (kN) =**	76.8	76.8	118.0	140.7	161.3	181.2	200.6	219.7
30	Design threshold :	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

Evaluation of bearing pressures between bearing elements for ballasted track

$A_{railcontact}$ (mm²) =	278	$\varphi_{subballast}$ (°) =	40.0
$A_{railbottom}$ (mm²) =	3,000	$A_{subballastbottom}$ (mm²) =	4,239,173
$A_{sleepertop}$ (mm²) =	3,000	Enter F_i or $F_{i,H}$ (kN) =	196.4
$w_{sleeperbottom}$ (mm) =	300		
$L_{eff\text{-}sleeperbottom}$ (mm) =	900	$p_{railhead}$ (MPa)=	706.5
$A_{sleeperbottom}$ (mm²) =	270,000	$p_{railbottom}$ (MPa)=	65.47
$d_{ballast}$ (mm) =	300	$p_{sleepertop}$ (MPa)=	65.47
$\varphi_{ballast}$ (°) =	30	$p_{sleeperbottom}$ (MPa)=	0.73
$A_{ballastbottom}$ (mm²) =	805,692	$p_{ballastbottom}$ (MPa)=	0.24
$d_{subballast}$ (mm) =	200.0	$p_{subballastbottom}$ (MPa)=	0.05

$K'_{B3\text{-}H}$ that considers the effect of Hertzian contact deformation on the dynamic impact due to a wheel flat





Our study that introduces the Bezgin – Kolukırık Equations

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Applications and Estimate Comparisons of Bezgin–Kolukırık Equations for Dynamic Impact Forces Because of Wheel Flats with Numerical Analysis Estimates and Instrumented Track Measurements

Niyazi Özgür Bezgin, Cengiz Kolukırık

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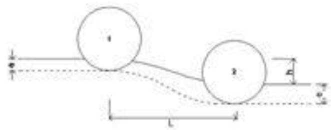
Abstract

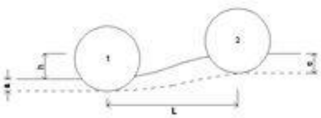
Bezgin–Kolukırık equations (K'_{B3} and $K'_{B3,H}$) are the last group of seven analytical equations based on the Bezgin Method. The method is based on the law of conservation of energy, rules of kinematics and a new concept, impact reduction factor, that describes the development of dynamic impact forces because of track and wheel roughness. K'_{B3} and $K'_{B3,H}$ estimate dynamic impact force factors because of wheel flats. $K'_{B3,H}$ includes the effect of Hertzian contact deformation on dynamic impact force factors. The proposed equations require up to six parameters to yield estimates. These parameters are: wheel diameter, wheel flat length, train speed, static wheel force transferred to the rail based on the tributary mass of the wheel, equivalent system stiffness of railway track and rolling stock, and length of Hertzian contact interface between wheel and rail. These equations empower users with the ability to estimate the highest values of the dynamic impact force factors because of wheel flats by manual calculations that yield realistic estimates comparable with estimates from advanced numerical methods and measurements obtained from instrumented test tracks. This paper presents the proposed Bezgin–Kolukırık equations followed by their application on hypothetical track and rolling stock conditions presenting a wide range of values for track and rolling stock stiffness, static wheel force, wheel diameters, train speed and wheel flat lengths. Estimates from the proposed equations are compared with the estimates of advanced numerical methods and experimental measurements from two previous papers.

Where are we now? Current status of the work.

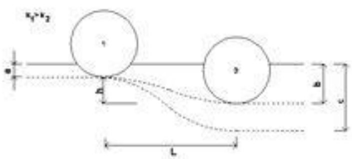
Kapsamı Genişletilmiş Bezgin Denklemleri



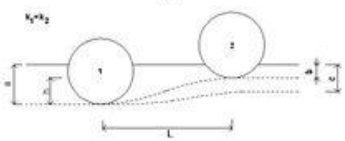
$$K'_{B,d} = 1 + \sqrt{\frac{2h}{a'}(1-f-s)} \qquad f = 1 - \frac{t_{düşüş}}{t_{geçiş}} = 1 - \frac{V}{L}\cdot\sqrt{\frac{2h}{g}}$$



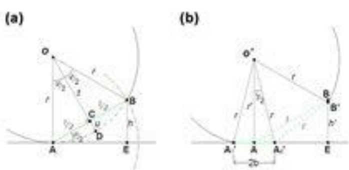
$$K'_{B,a} = 2\sqrt{\frac{h}{2a'}(1-f-s) + 1} - 1 \qquad K_j = \frac{2h_1}{g}\cdot\left(\frac{v}{L}\right)^2$$



$$K'_{B1} = 1 + \sqrt{2\left[(1-f-s)\left(1-\frac{a'}{b'}\right)\right]}$$



$$K'_{B2} = \sqrt{2\left[1+f+s+\frac{a'}{b'}.(1-f-s)\right]} - 1 \qquad K_j = \frac{2h_1}{g}\cdot\left(\frac{v}{L}\right)^2$$



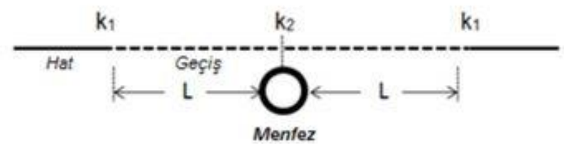
$$K'_{B3} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v}{a'.\varphi.\sqrt{r.g}}} \qquad f = 1 - \frac{t_{düşüş}}{t_{dönüş}} = 1 - \frac{4.v.\sin\frac{\varphi}{2}}{\varphi.\sqrt{r.g}}$$

$$K'_{B3,H} = 1 + 2.\sin\frac{\varphi}{2}\sqrt{\frac{2.l.v.\left(\frac{h'}{h}\right)}{a'.\varphi.\sqrt{r.g}}}$$

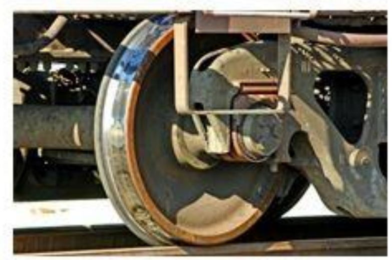
(Bezgin ve Kolukırık denklemleri)

Sol resim kaynağı: U.S. Department of Transportation Federal Railroad Administration A Study of Environmental and Track Factors that Contribute to Abrasion Damage of Concrete Ties. Riding, Peterman, Guthrie, Brueseke, Mosavi, Daily

Sağ resim kaynağı: Haoyu Wang, Valeri Markine Corrective countermeasure for track transition zones in railways: Adjustable fastener. Engineering Structures, 169 (2018) 1-14



Resim kaynağı: N. Ö, Bezgin, "Kapsamı genişletilmiş Bezgin Denklemlerinin tanıtılması," Demiryolu Mühendisliği, no. 10, pp. 1-16, Haziran 2019.

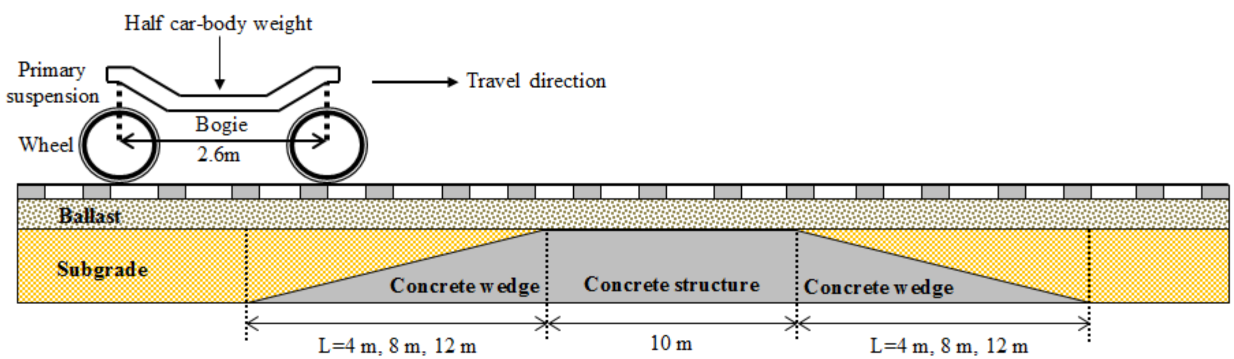


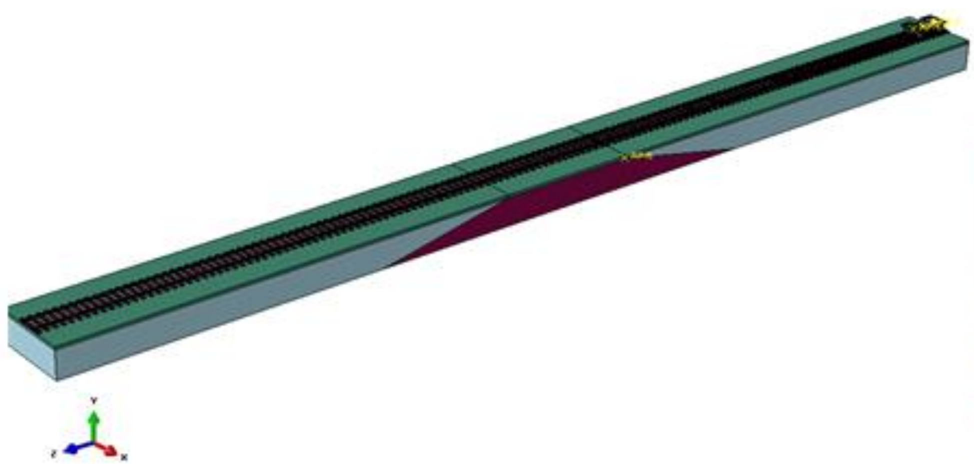
Resim kaynağı: http://www.mermecgroup.com/inspect/train-monitoring/1024/wheel-impact-load.php

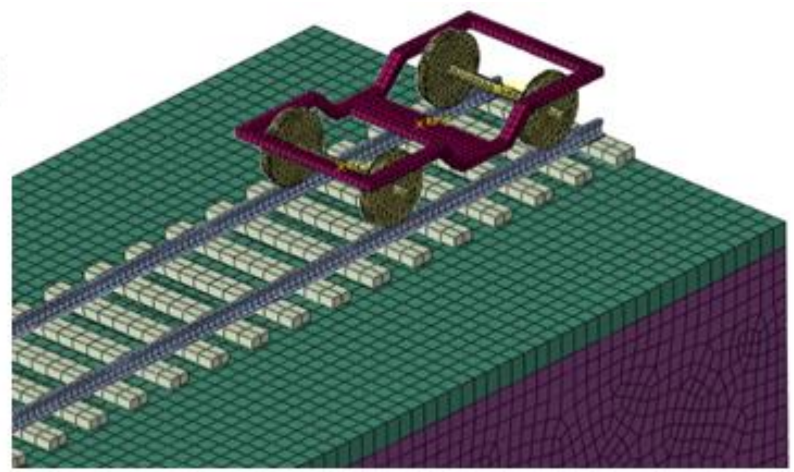
Collaboration with Network Rail

Collaboration with Dr. Mohamed Wehbi, Senior Design Engineer Track Bed Design & Investigation Team of Network Rail

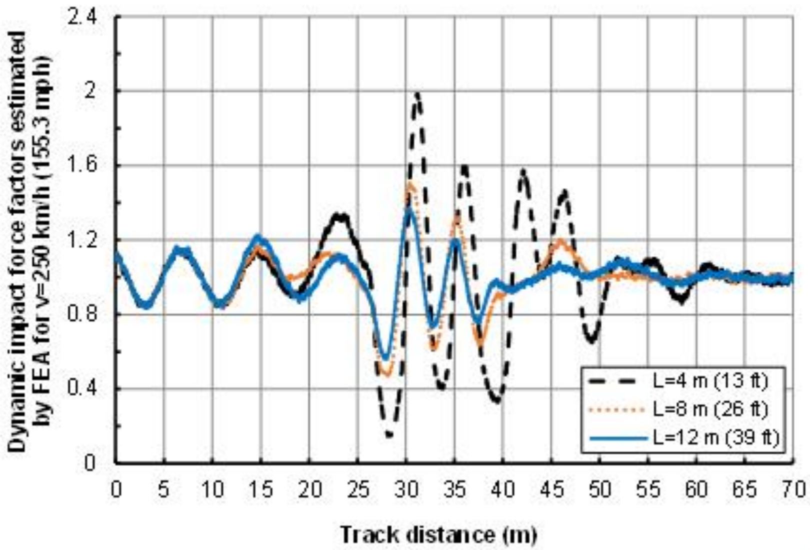
- The nature of the collaboration is to investigate the use of the Bezgin Method for the analysis of rough track due to variations in track stiffness and track profile.

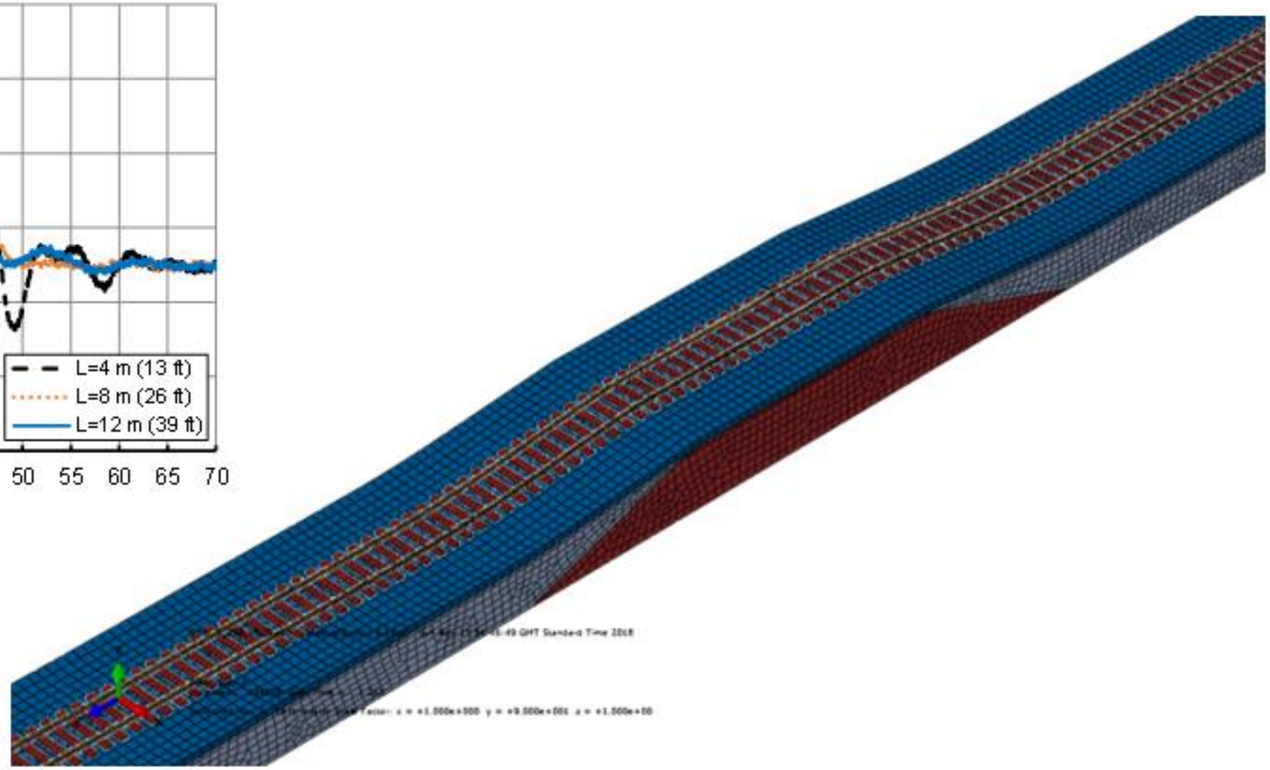






Extensive comparisons of estimates with numerical analysis





Our collaboration yielded:

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Advancement and Application of the Bezgin Method to Estimate Effects of Stiffness Variations along Railways on Wheel Forces

Niyazi Özgür Bezgin, Mohamed Wehbi

First Published April 26, 2019 | Research Article | Check for updates

https://doi.org/10.1177/0361198119835805

Article information

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Abstract

The need for an analytical method that one can apply manually to estimate dynamic impact forces on railway tracks that occur because of varying track stiffness or track profile initiated a study to develop an analytical method named as the Bezgin Method. The advancement of this method presented in this paper includes an extension of a set of equations developed and introduced by the first author earlier as the Bezgin Equations using the proposed method and development of a new equation. In addition to track stiffness taken into consideration in the equations introduced earlier, the Extended Bezgin Equations presented in this paper take into account bogie stiffness, wheel spring stiffness, Hertzian contact stiffness, and a factor for damping. The new equation takes into account the effect of vertical wheel acceleration as a train transitions to a stiffer structure or transitions along an ascending track profile. The paper unites and applies these equations to estimate wheel forces that develop along stiffness transition zones by considering an array of train speeds for an array of track stiffness ratios and representative values for track profile deviations along the transitions. Final section of the paper includes elaborate finite element analyses of structural track models that involve transitions of soil supported ballasted railway tracks with concrete based ballasted tracks along various transition lengths and compares their estimates for dynamic impact force factors with those estimated by the Extended Bezgin Equations. The paper concludes with a discussion of the potential uses, benefits, and the value of the Bezgin Method for railway engineering.

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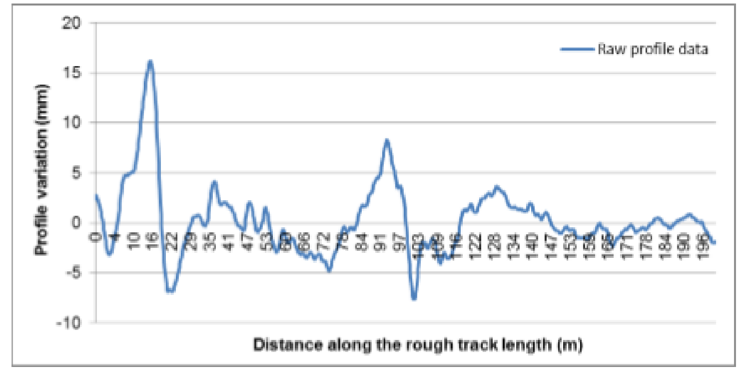

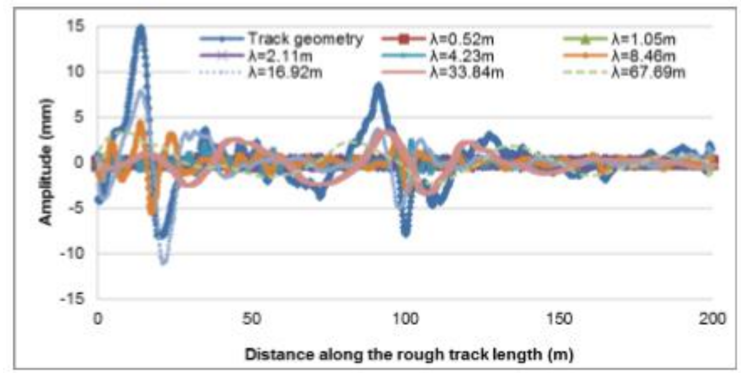

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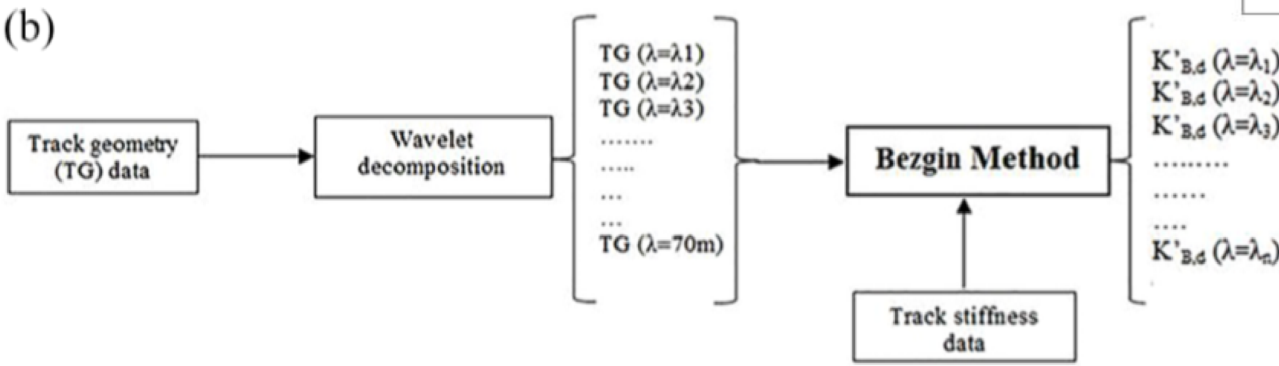
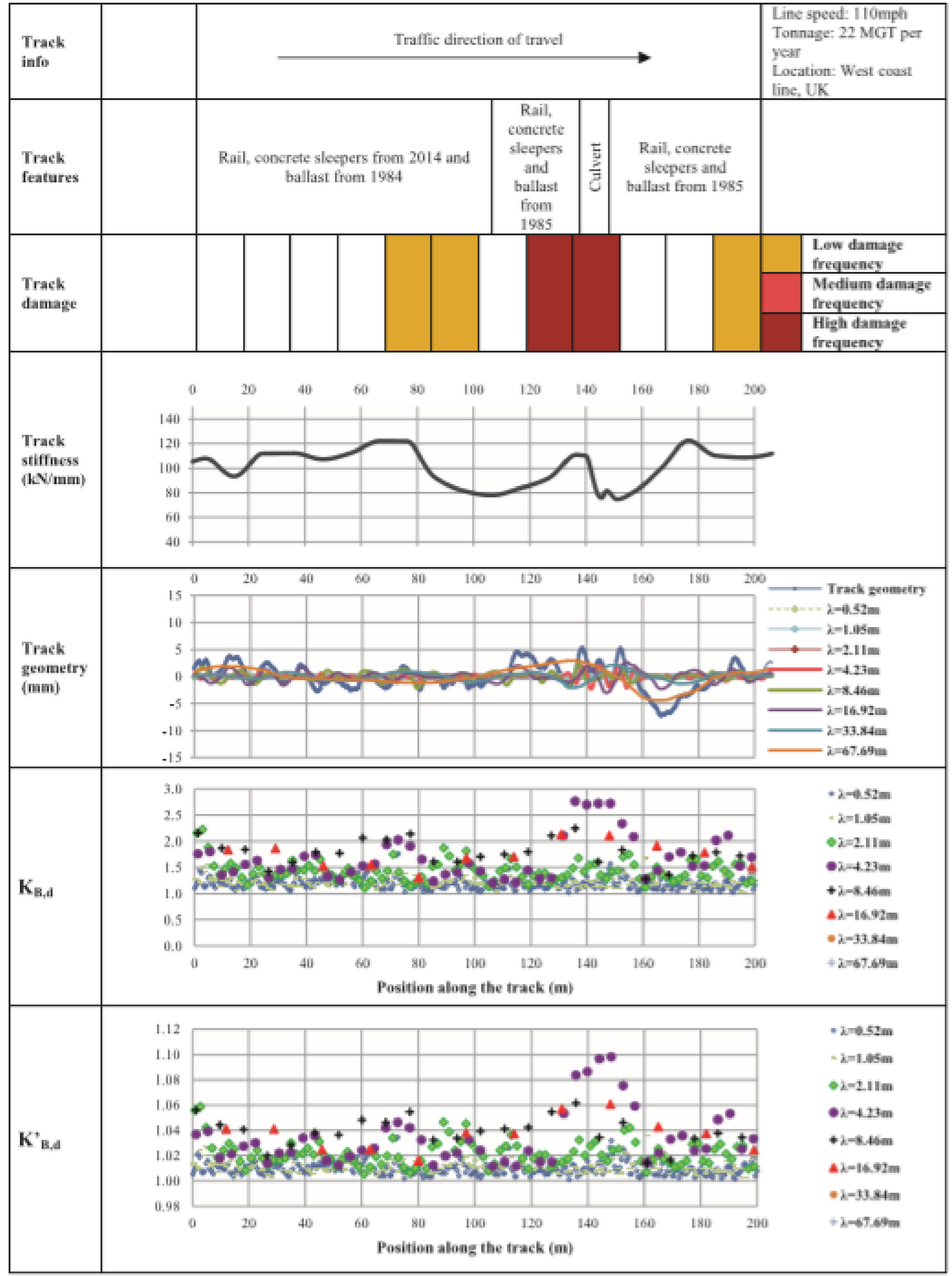


Application over case studies and site specific data



Our collaboration yielded:

Collaboration with SNCF

Collaboration with Railway Dynamics Team of SNCF Réseau

- The nature of the recently initiated collaboration is to investigate the use of the Bezgin Method for the analysis of rough wheel profiles and track defect singularities.
- Comparison studies are underway that compare the highest force estimates of advanced numerical model analysis for wheel flats and rail joints with the estimates of K'_{B3}.

Coupling Multi-body Simulation of Vehicle Dynamics and Finite Elements Models: the Effect of Flexible Wheelset and Track

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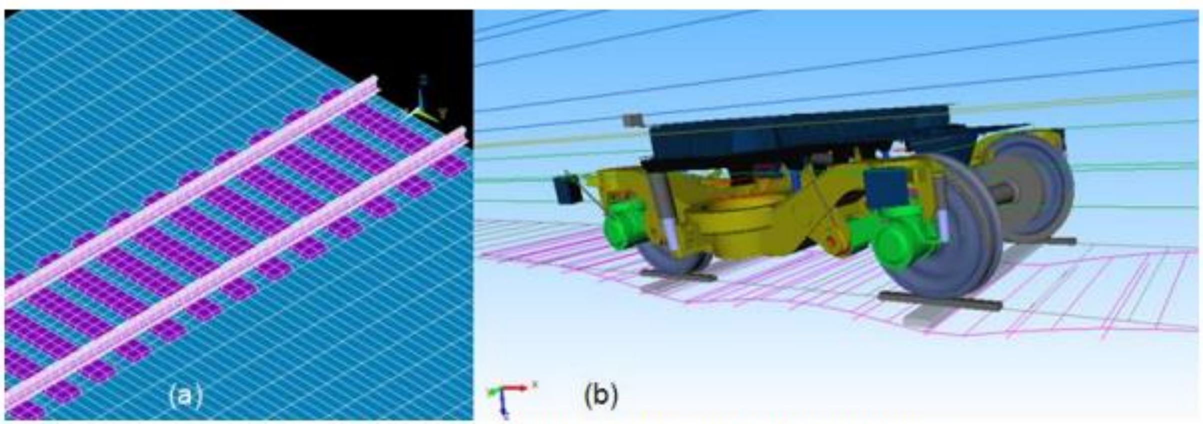

Fig. 7: FE model of flexible track and its deformation

Conclusions

- All else being the same, the same wheel flat on two different wheel diameters will generate different impacts which are inversely related to the wheel diameter.
- There is currently no consensus among agencies and railway authorities with regards to the limitation of wheel flats operating on railways.
- The issue is complicated not only due to speed and weight of the service but also due to differences in the weight distributions of the rolling stock.
- Nevertheless, the engineer must set a serviceable and a stable load path between the wheel and rail contact and the subgrade.
- Accumulating damage on the railhead paves the way to variations in railway profile and stiffness, resulting in an array of dynamic impact forces on the railway track.
- There must be a clear understanding between the owners of the railway track and those operating the trains with regards to the allowable extent of wheel flats, which has the potential to damage both the track and the wheel.
- A single limit on the flat does not satisfy all operational cases.

Conclusions

- The research continues with the application of the equations produced by the Bezgin Method to estimate the peak dynamic impact forces due to track and wheel roughness.
- To this end, further comparisons with advanced numerical modelling and field data are needed.
- I look forward to establishing more collaborations and extending the breadth and depth of existing collaborations to introduce the proposed method and the equations to wider audiences.

- I have a request for site data to correlate the estimated dynamic impact forces to observed track and wheel damage.
- I request data from advanced numerical modelling of rail joints, wheel flats, turnout crossings to compare with the estimates of the proposed equations.


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Thank you
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