DYNAMIC ANALYSIS OF RAILWAY VEHICLE-TRACK INTERACTIONS DUE TO WHEEL FLAT WITH A PITCH-PLANE VEHICLE MODEL

Presentation by
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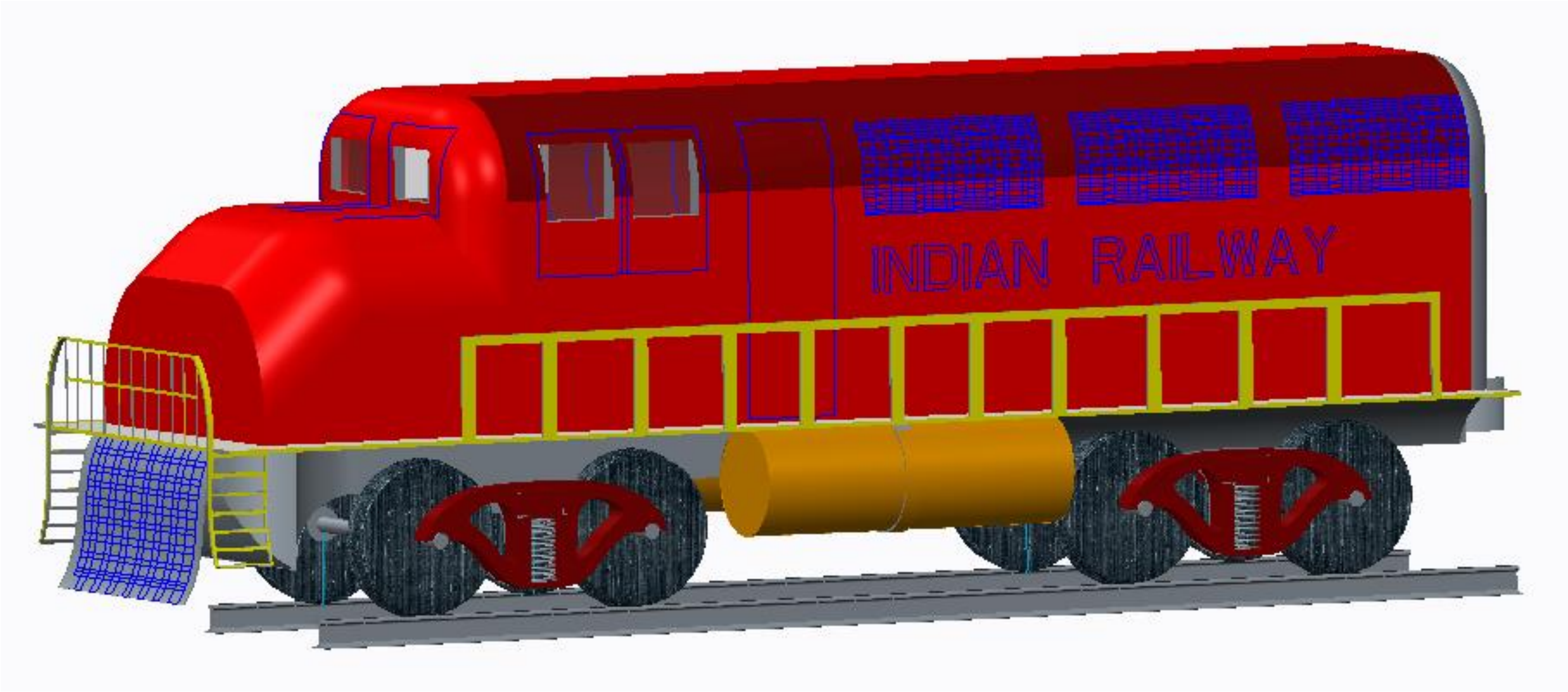
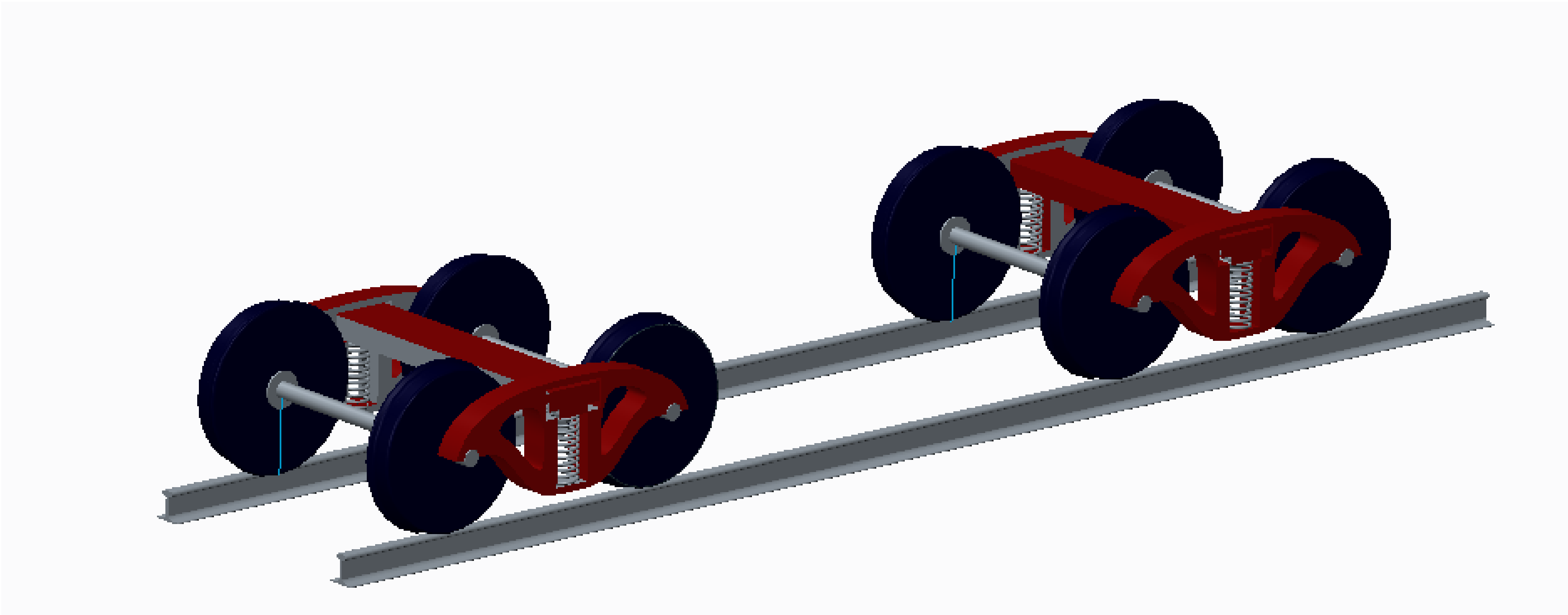
Solid Model



Part Model of Bogie

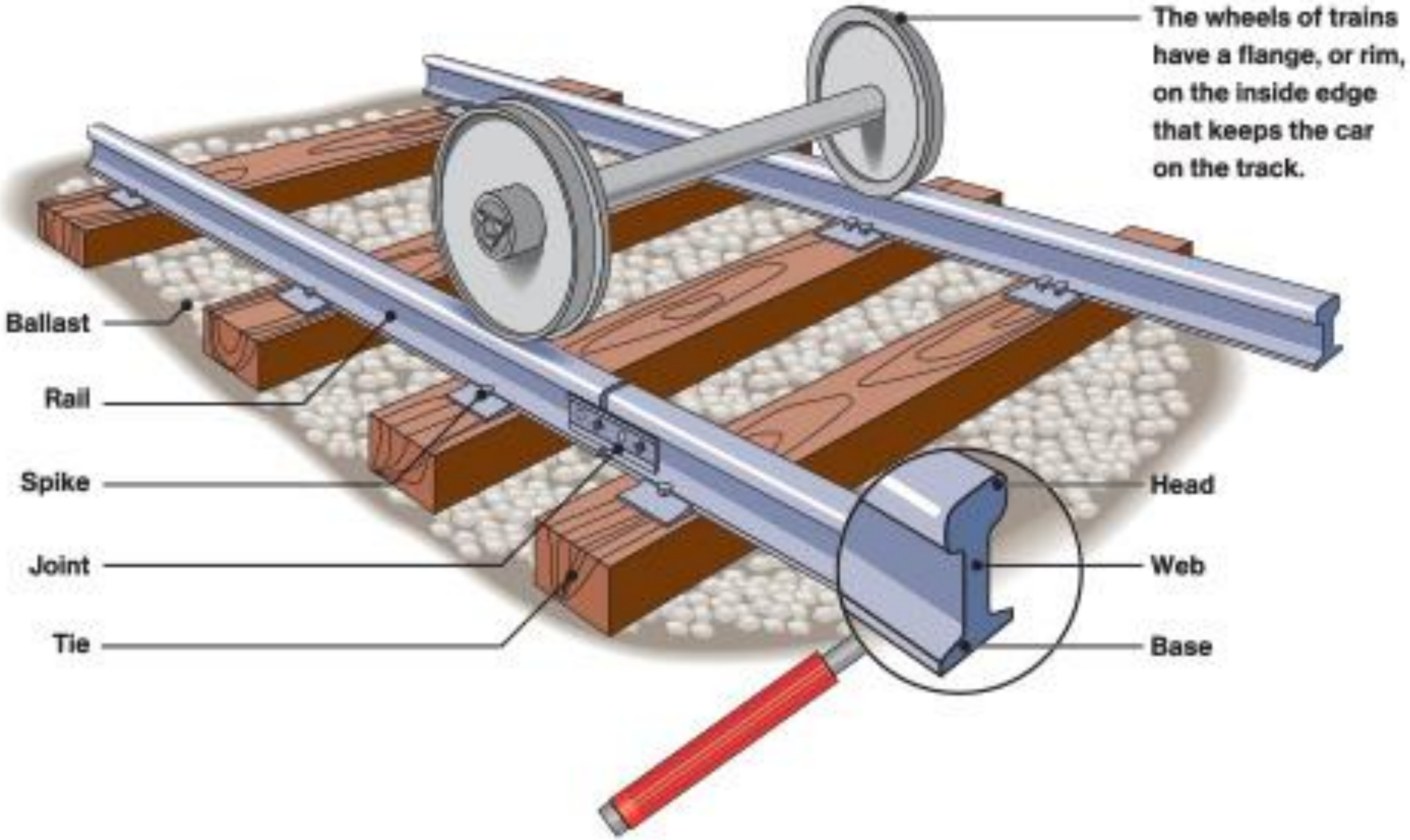


Introduction

- The existence of defects in a railway wheel is one of the main sources of railway vehicle-track abnormal vibrations.

- Wheel flat is the most common type of wheel defect encountered by the railway industry, caused by use of the emergency brake, or slip and slide conditions that causes wheels to lock up while the train is still moving. With the significant increase of train speed and axle load, the vibration of the coupled vehicle and track system due to wheel flat is further intensified and the safe operation of trains is reduced.

- The repeated dynamic loads due to wheel flats will cause failure and fatigue damage of the vehicle and track components. A comprehensive study in the presence of wheel flat is thus necessary for prediction of the impact force generated at the interfaces of different components of vehicle-track system.


The wheels of trains
have a flange, or rim,
on the inside edge
that keeps the car
on the track.
Ballast
Rail
Spike
Joint
Tie
Head
Web
Base

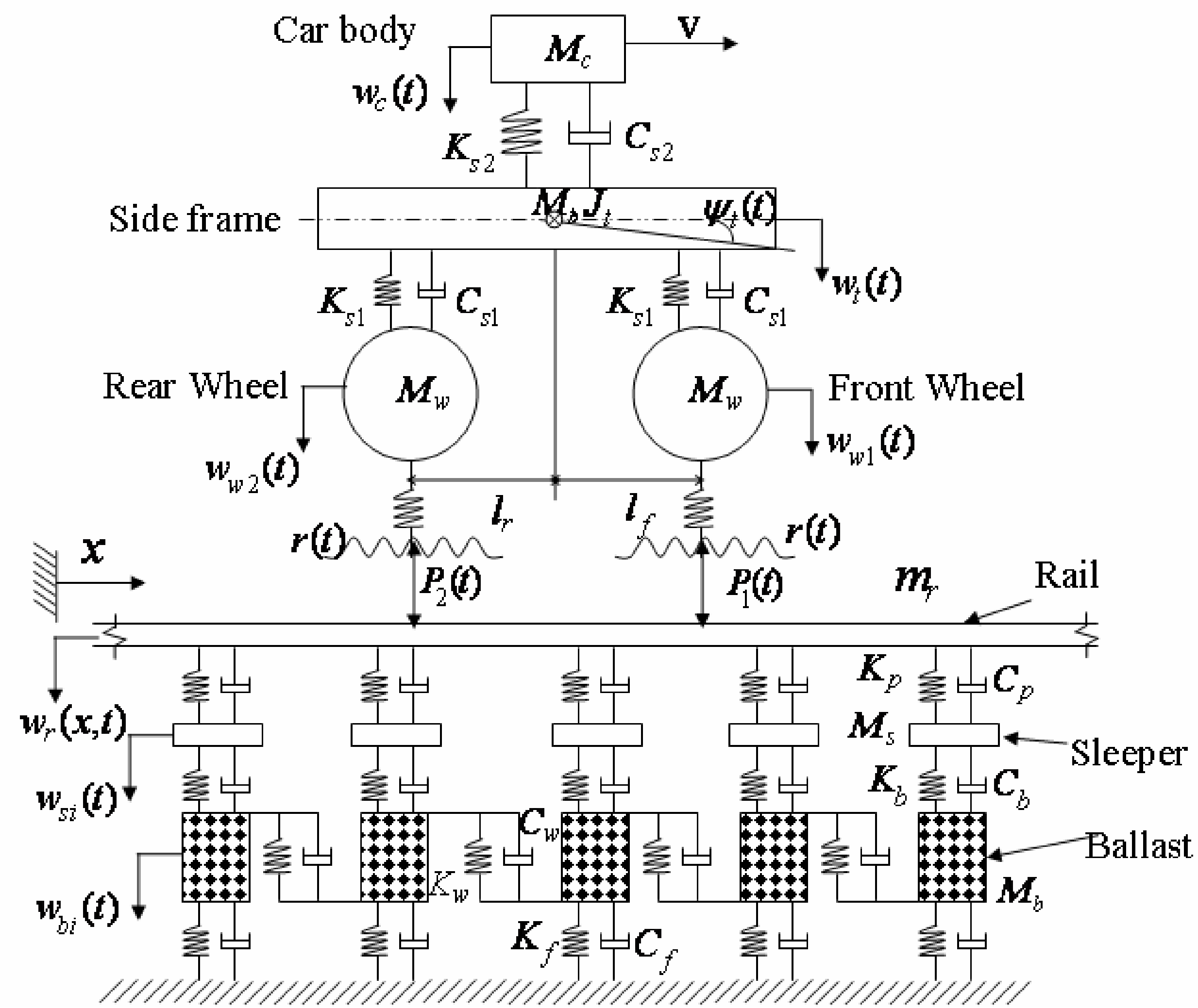
- Two types of track models are generally employed in the study of vehicle-track interactions. Early track system studies considering rail as a discretely supported beam is now widely used for modelling of wheel-rail interactions. Vehicle-track interaction studies in general consider track as a continuous system as Euler-Bernoulli beam.

- In the present case, a dynamic computational model for the vehicle and track is formulated by means of modal analysis method. An idealized wheel flat with the rounded corner is included in the wheel-rail contact model. The coupled ordinary differential equations are solved for the vehicle-track system.

- The quarter car model is considered with 5 DOF

- The responses in terms of impact force of various vehicle and track components have been evaluated and analysed.

Quarter car model



M_c = mass of car body
M_t = Bogie mass
M_w = wheel mass
$w_c(t)$ = vertical motion of car
$w_t(t)$ =vertical motion of bogie
$\psi_t(t)$ =pitch motion of bogie
$w_{w1}(t)$ =vertical motion of wheel 1
$w_{w2}(t)$= vertical motion of wheel 2

Car body bounce motion:

$$M_c\ddot{w}_c + C_{s2}\dot{w}_c + K_{s2}w_c - C_{s2}\dot{w}_t - K_{s2}w_t = 0$$

Bogie bounce motion:

$$M_t\ddot{w}_t + K_{s1}\left(w_t + l_f\psi_t - w_{w1}\right) + K_{s1}(w_t - l_r\psi_t - w_{w2}) + K_{s2}(w_t - w_c)$$
$$+ C_{s1}\left(\dot{w}_t + l_f\dot{\psi}_t - \dot{w}_{w1}\right) + C_{s1}\left(\dot{w}_t - l_r\dot{\psi}_t - \dot{w}_{w2}\right) + C_{s2}(\dot{w}_t - \dot{w}_c) = 0$$

Bogie pitch motion:

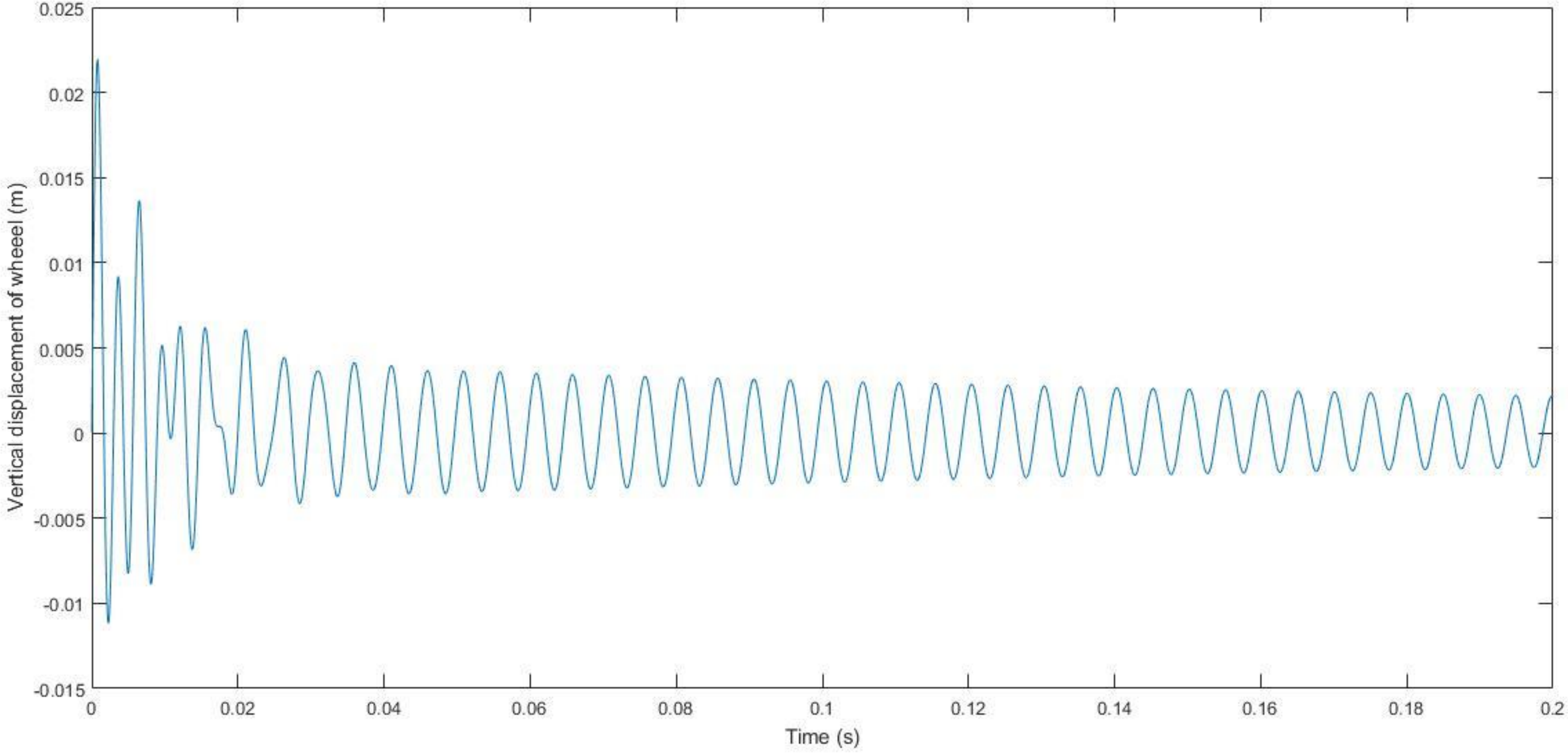
$$J_t\ddot{\psi}_t + K_{s1}l_f\left(w_t + l_f\psi_t - w_{w1}\right) - K_{s1}l_r(w_t - l_r\psi_t - w_{w2}) + C_{s1}l_f\left(\dot{w}_t + l_f\dot{\psi}_t - \dot{w}_{w1}\right)$$
$$- C_{s1}l_r(\dot{w}_t - l_r\dot{\psi}_t - \dot{w}_{w2}) = 0$$

Front wheel vertical motion:

$$M_w\ddot{w}_{w1} + C_{s1}(\dot{w}_{w1} - \dot{w}_t) + K_{s1}(w_{w1} - w_t) - C_{s1}l_f\dot{\psi}_t - K_{s1}l_f\psi_t + P_1(t) = 0$$

Rear wheel vertical motion:

$$M_w\ddot{w}_{w2} + C_{s1}(\dot{w}_{w2} - \dot{w}_t) + K_{s1}(w_{w2} - w_t) + C_{s1}l_r\dot{\psi}_t + K_{s1}l_r\psi_t + P_2(t) = 0$$



0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
Vertical displacement of wheeel (m)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
Time (s)

Deflection Equations of continuous rail track for Euler beam

$$EI\frac{\partial^4 w_r(x,t)}{\partial x^4} + m_r\frac{\partial^2 w_r(x,t)}{\partial t^2} = -\sum_{i=1}^{N} F_{rsi}(t)\delta(x-x_i) + \sum_{j=1}^{2} P_j{}'(t)\delta(x-x_j)$$

Total Vertical force acting at j'th rail and wheel interface

$$P_j'(t) = P_j(t) + [0.5(M_c + M_t) + M_w]g$$

Where $P_j(t)$ is contact force

$F_{rsi}(t)$ is force developed at the ith rail/sleeper interface, it is given by

$$F_{rsi}(t) = K_{pi}[w_r(x_i,t) - w_{si}(t)] + C_{pi}[\dot{w}_r(x_i,t) - \dot{w}_{si}(t)$$

Hertzian Contact Theory

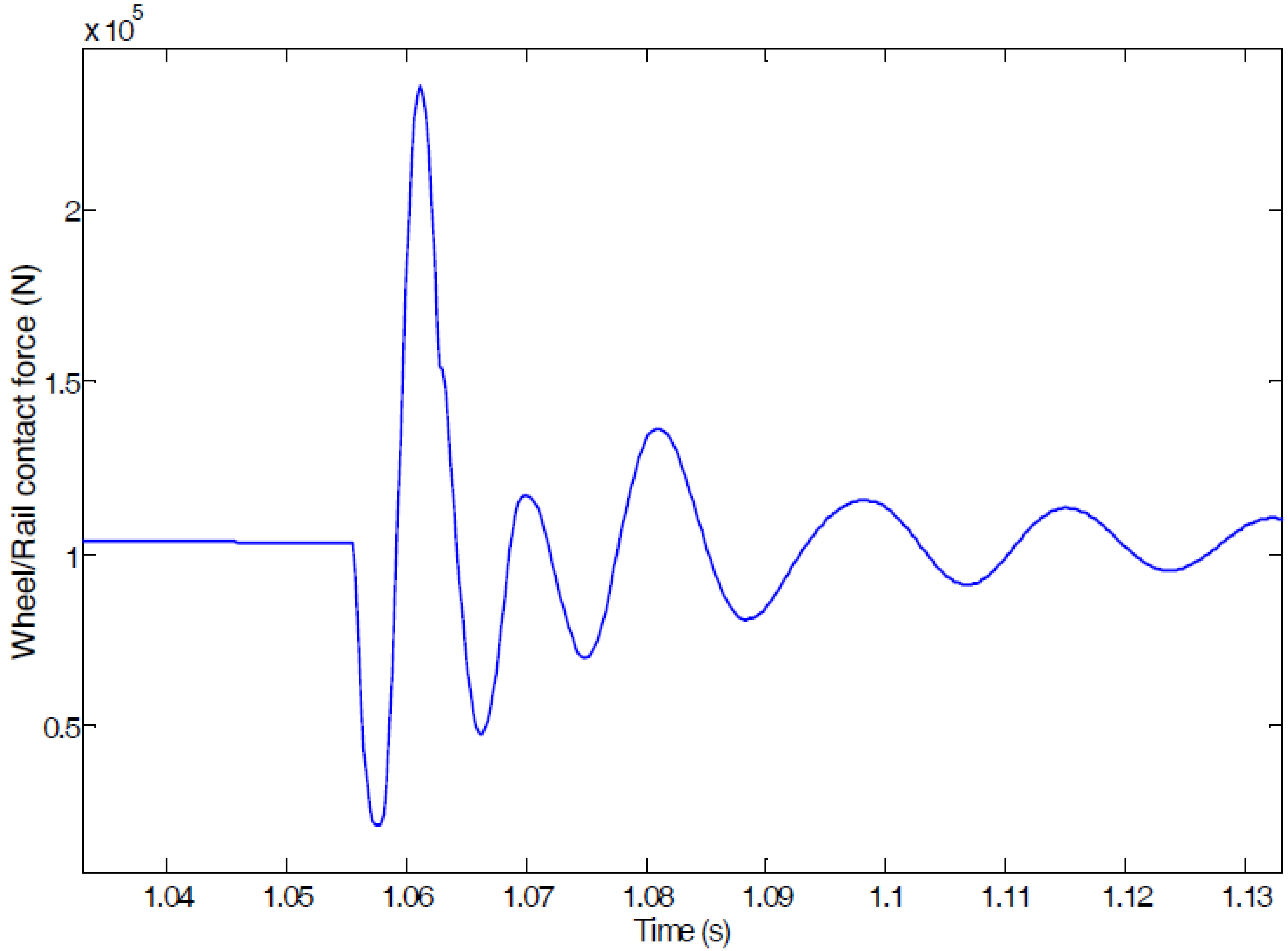
Wheel/ Rail $Contact\ Force\ P(t) = C_H \Delta z(t)^{\frac{3}{2}}$

Overlap in Vertical direction $\Delta z(t) = w_w(t) - w_r(x,t) - r(t)$

Haversine Flat expression

Wheel Flat Function $r = \frac{1}{2} D_f [1 - \cos\left(\frac{2\pi x}{L_f}\right)]$

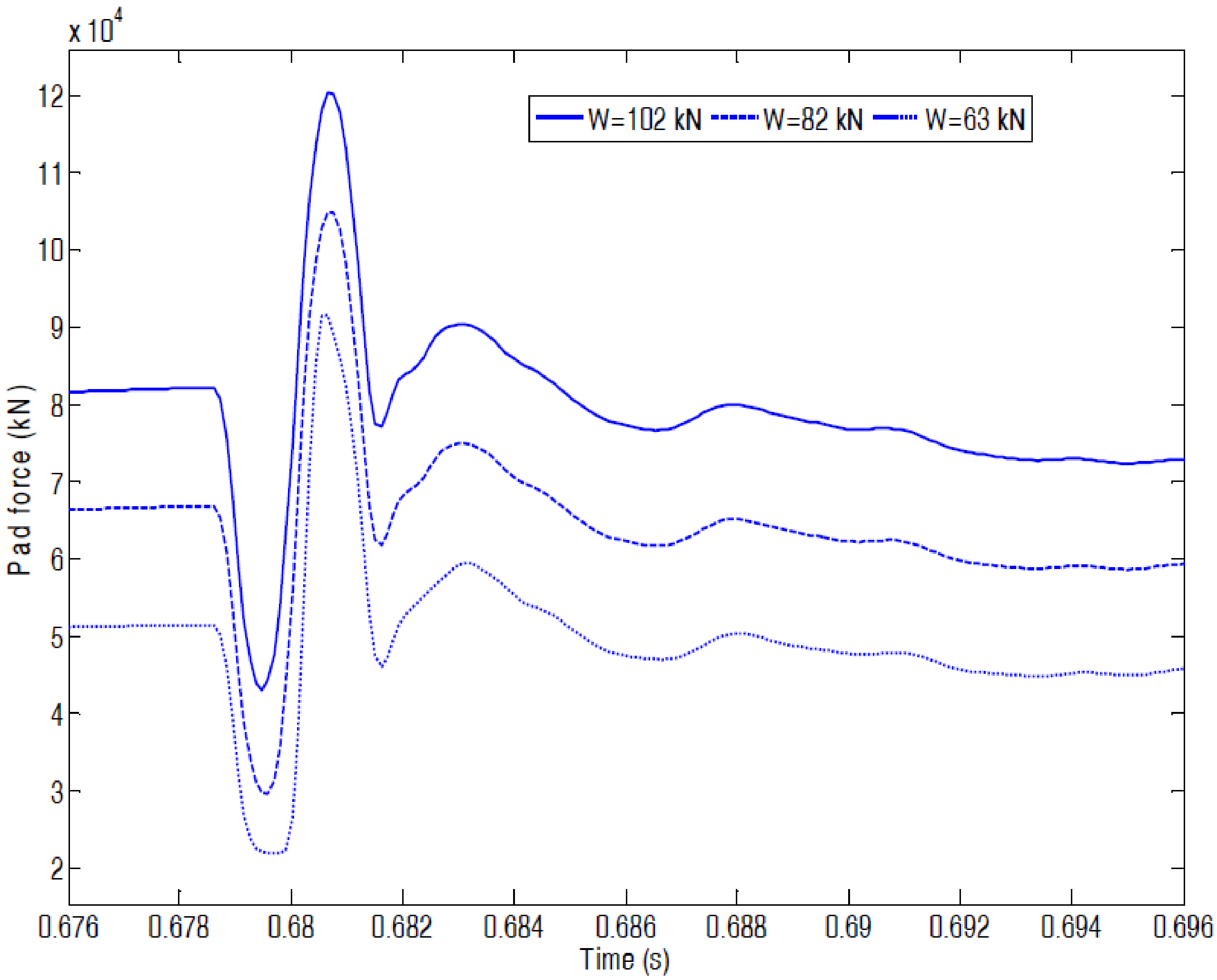
Where
D_f-flat depth, L_f - length of flat
X- longitudinal coordinate of the contact point within the flat
w_w -wheel deflection
w_r - Rail deflection



(a) front wheel-rail impact with flat

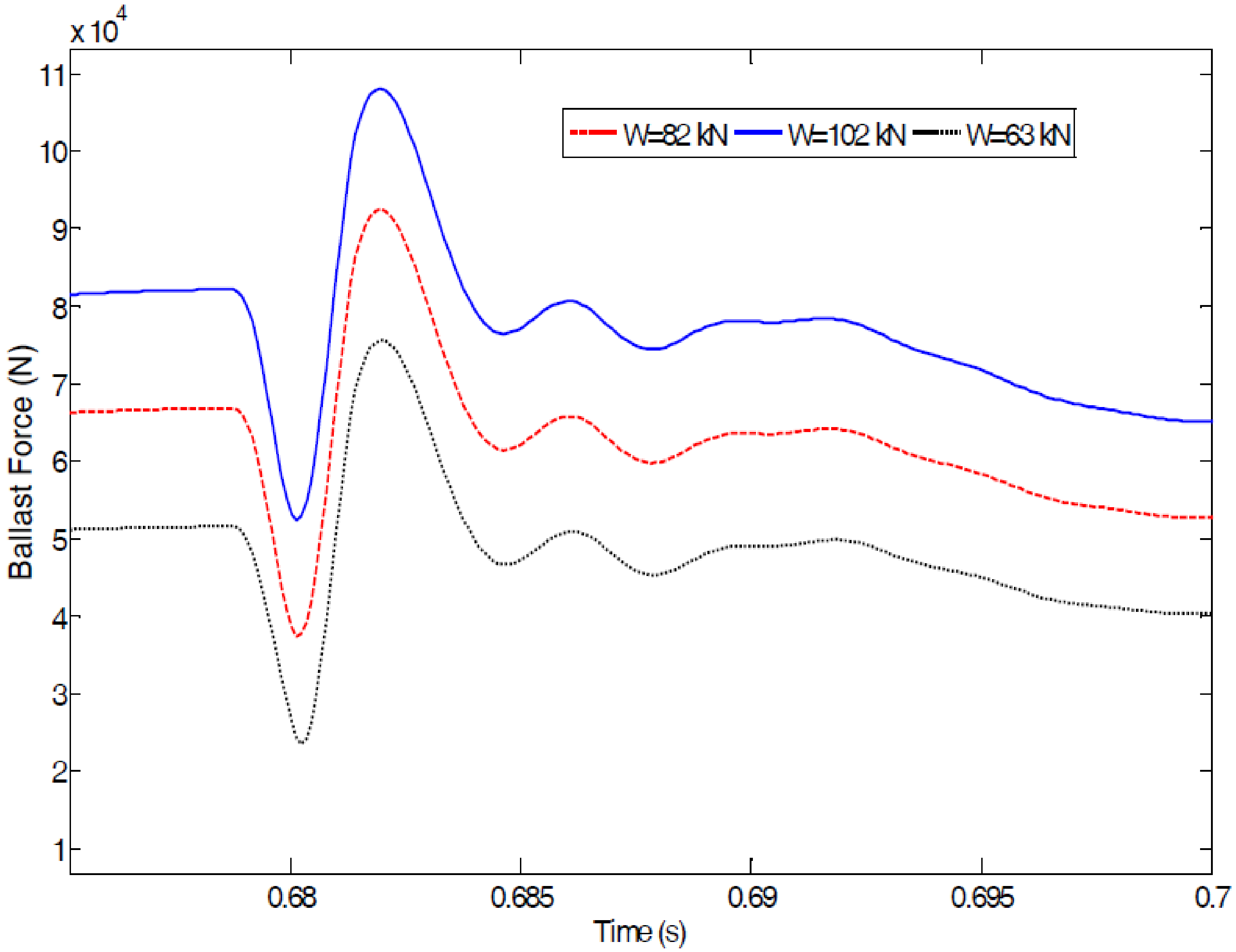
$F_{rsi}(t)$ is force developed at the ith rail/sleeper interface, it is given by

$$F_{rsi}(t) = K_{pi}[w_r(x_i,t) - w_{si}(t)] + C_{pi}[\dot{w}_r(x_i,t) - \dot{w}_{si}(t)]$$



$F_{sbi}(t)$ is force developed at the ith sleeper/ballast interface, it is given by

$$F_{sbi}(t) = K_{bi}[w_{si}(t) - w_{bi}(t)] + C_{bi}[\dot{w}_{si}(t) - \dot{w}_{bi}(t)] + K_{wi}(w_{bi} - w_{b+i}) + C_{wi}(\dot{w}_{bi} - \dot{w}_{b+i}) + K_{wi}(w_{bi} - w_{b-i}) + C_{wi}(\dot{w}_{bi} - \dot{w}_{b-1})$$



Remedies:

- If there is small flat spot, we can use that rail-wheel
- Fault will be removed later in lathing
- Even if we repaired the wheel, that will be the weak spot and chances of failure is high
- If the flat spot is large, then we have to replace the whole wheel set
- Then there will be insufficient clearance between rolling surface and break block

The different values are taken as mentioned in the table

Table 1: Nominal simulation parameters

Sym.	Parameter	Value
M_c	Car body mass (quarter car)	19400 kg
M_t	Bogie mass (half)	500 kg
M_w	Wheel mass	500 kg
J_t	Bogie mass moment inertia	176 kg-m^2
K_{s1}	Primary suspension stiffness	788 MN/m
C_{s1}	Primary suspension damping	3.5 kN-s/m
K_{s2}	Secondary suspension stiffness	6.11 MN/m
C_{s2}	Secondary suspension damping	158 kN-s/m
l_t	Wheelset distance	1.25 m
R	Wheel radius	0.42 m
L_f	Flat length	52 mm
D_f	Flat depth	0.4 mm
C_H	Hertzian spring constant	87 GN/m$^{3/2}$
m_r	Rail mass per unit length	60.64 kg/m
EI	Rail bending stiffness	6.62 MN-m^2
M_s	Sleeper mass	118.5 kg
M_b	Ballast mass	739 kg
K_p	Railpad stiffness	120 MN/m
K_b	Ballast stiffness	182 MN/m
K_w	Ballast shear stiffness	147 MN/m
K_f	Subgrade stiffness	78.4 MN/m
C_p	Railpad damping	75 kN-s/m
C_b	Ballast damping	58.8 kN-s/m
C_w	Ballast shear damping	80 kN-s/m
C_f	Subgrade damping	31.15 kN-s/m
l_s	Sleeper distance	0.6 m
N	No. of sleepers	100

Summary

- We modelled rail wheel as multi degree of freedom spring mass system
- Then formulated the equations and solved in matlab.
- Then we plotted various graphs and studied the effect of flat wheel

Paper:

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Thank you