

Vehicle Dynamics

ME5670



LONGITUDINAL DYNAMIC ANALYSIS OF RAILWAY VEHICLE

GROUP 12

Dibya Ranjan Barik (ME18MTECH11009)

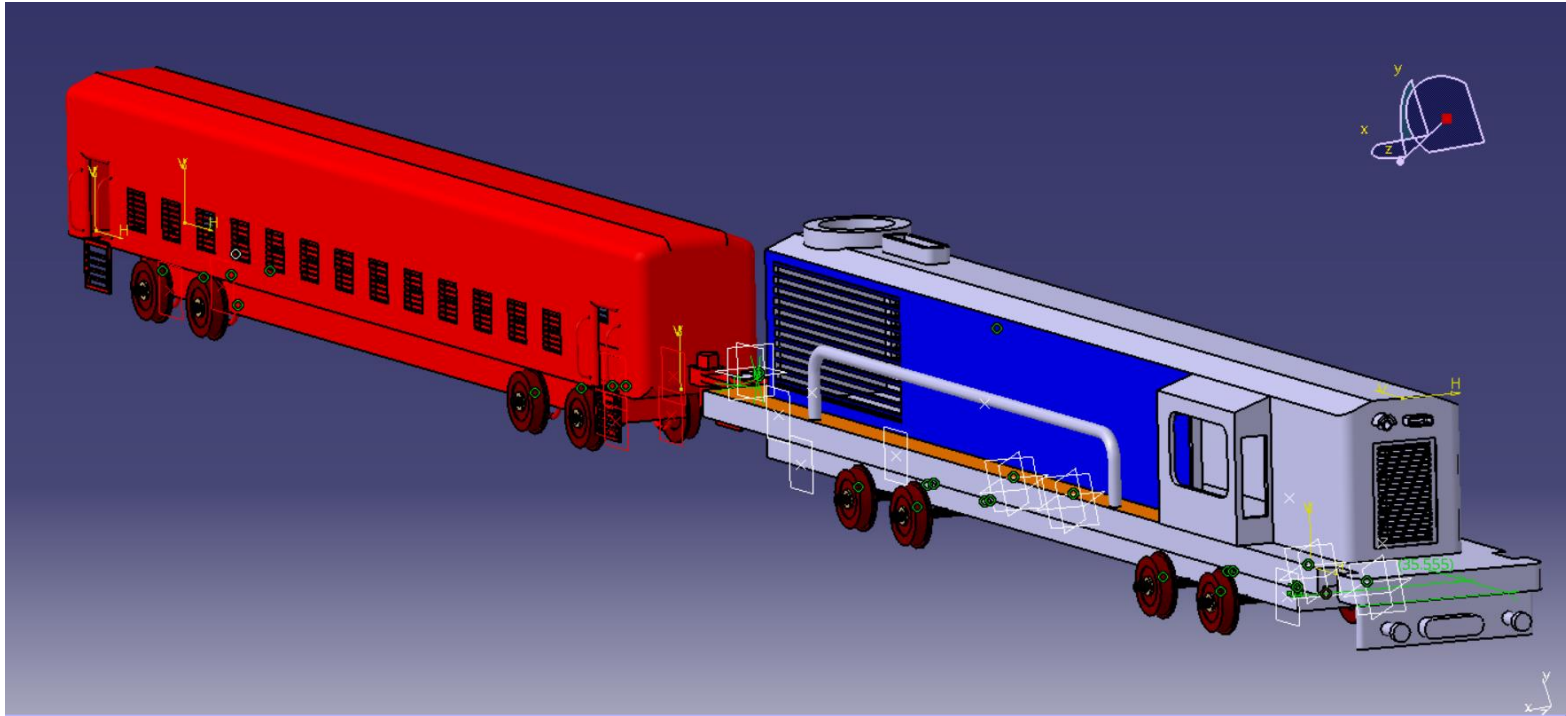
Dheeraj (ME18MTECH11022)

A Sarath (ME18MTECH11024)

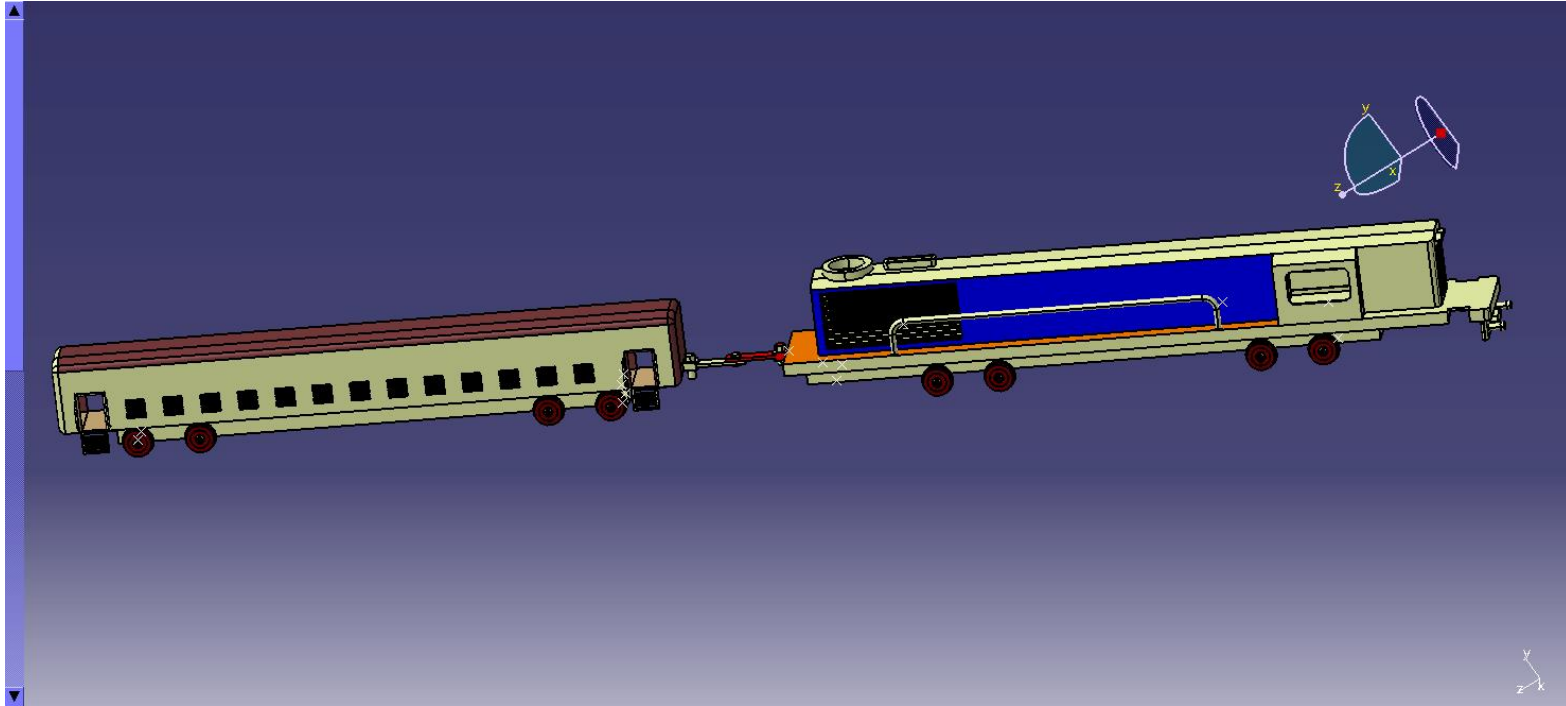
Nikhil Dilip Kumbhar (ME18MTECH11031)

Aashish Shaju (ME18MTECH11032)

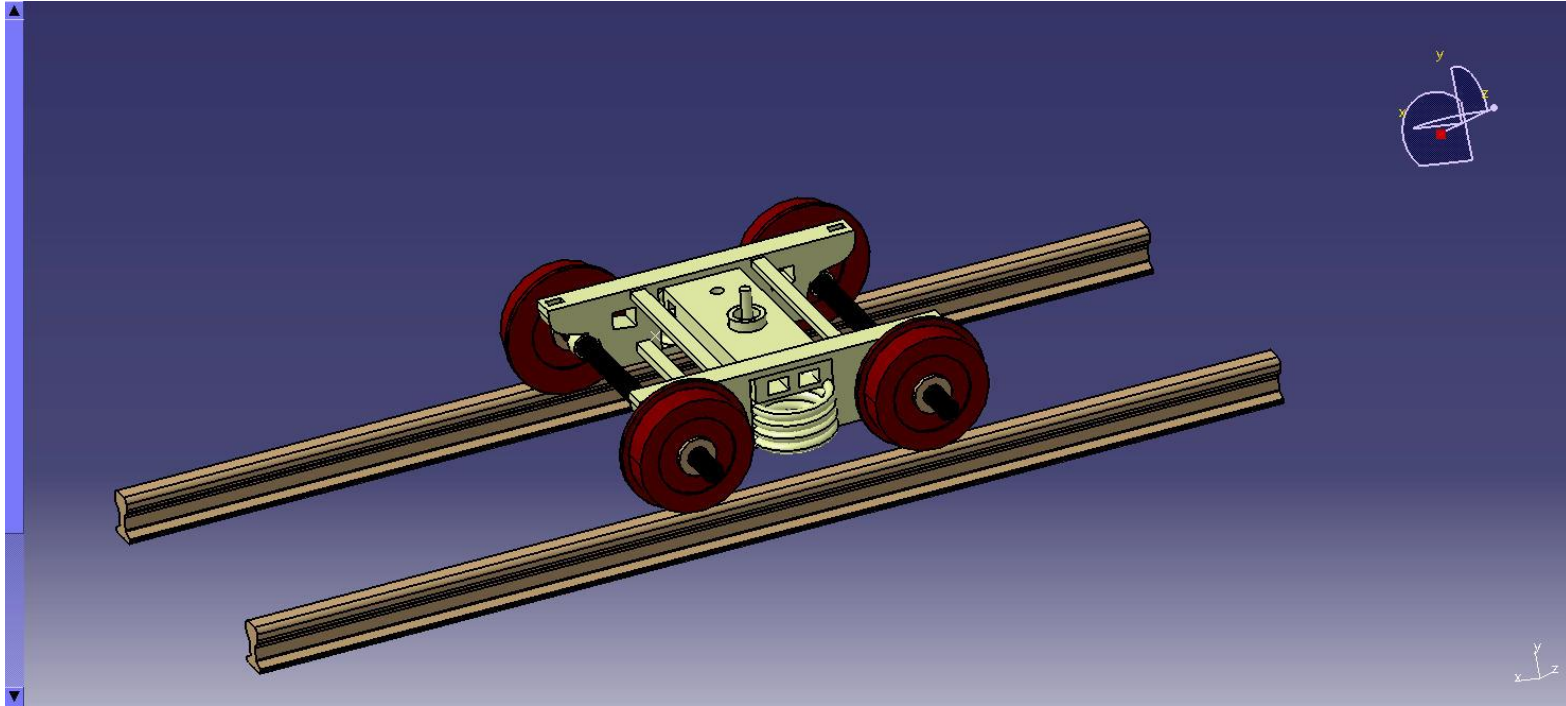
CAD MODEL – FULL ASSEMBLY



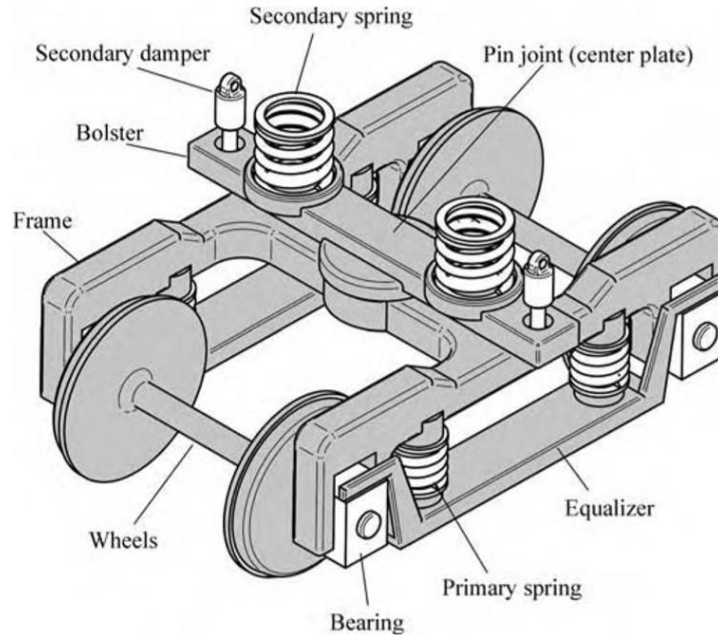
CAD MODEL – FULL ASSEMBLY



CAD MODEL – BOGIE ASSEMBLY



INTRODUCTION



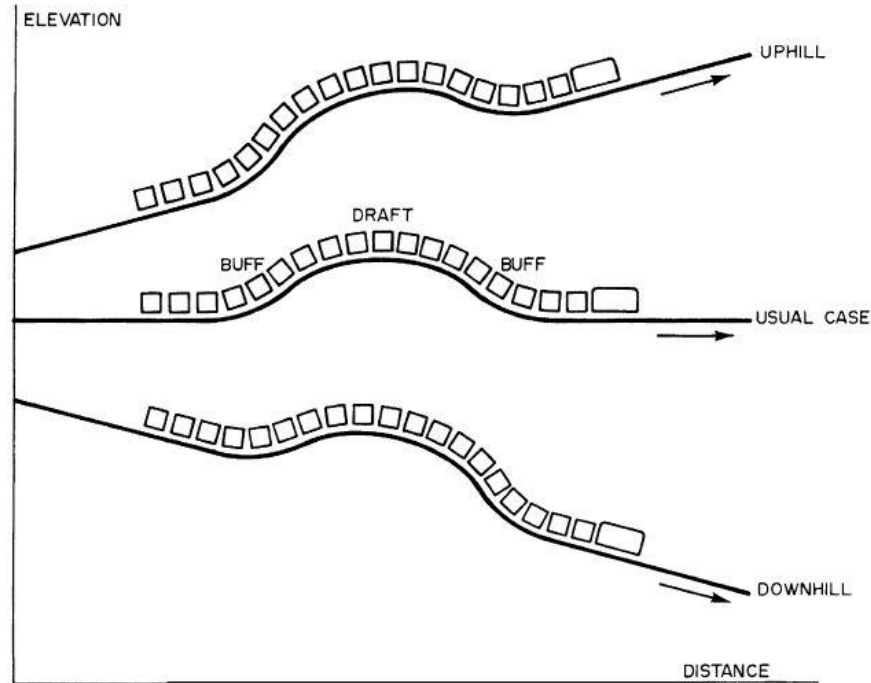
Bogie

The bogies represent complex systems that include frames and wheel sets that can have independent motions.

The wheel sets, which can rotate freely about their own axes, are connected to the frame using primary suspensions, while the frame is connected to the bolster using a pin joint, and the bolster is connected to the car body using the secondary suspensions.



LONGITUDINAL ANALYSIS



A train on uphill, level, and downhill tracks and draft (tension) and buff (compression) regions along the train length

WHY LONGITUDINAL DYNAMICS ???

- The problems caused by longitudinal forces include broken draft gears, generally caused by excessive longitudinal draft forces.
- These are problems of cars being pulled off the inside of curves.
- In addition, levels of wear and fatigue involving broken components can be attributed to certain levels of longitudinal load.



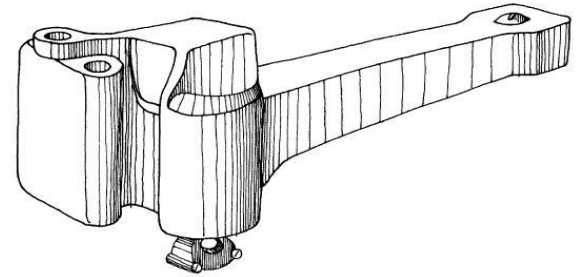
TRAIN COMPONENTS - COUPLER

The coupler is the longitudinal element that connects adjacent vehicles.

When couplers connect two vehicles, a solid connection is not formed, but instead the couplers act as a dead-band spring in which the width denotes the *coupler slack*.

Coupler slack is required so that the locomotive(s) can start a train easily.

During braking, coupler slack develops run-in forces, which can be large enough to cause train derailments.

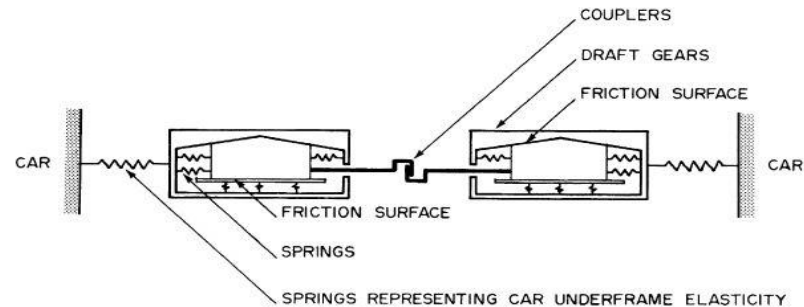


Coupler



TRAIN COMPONENTS - DRAFT GEARS

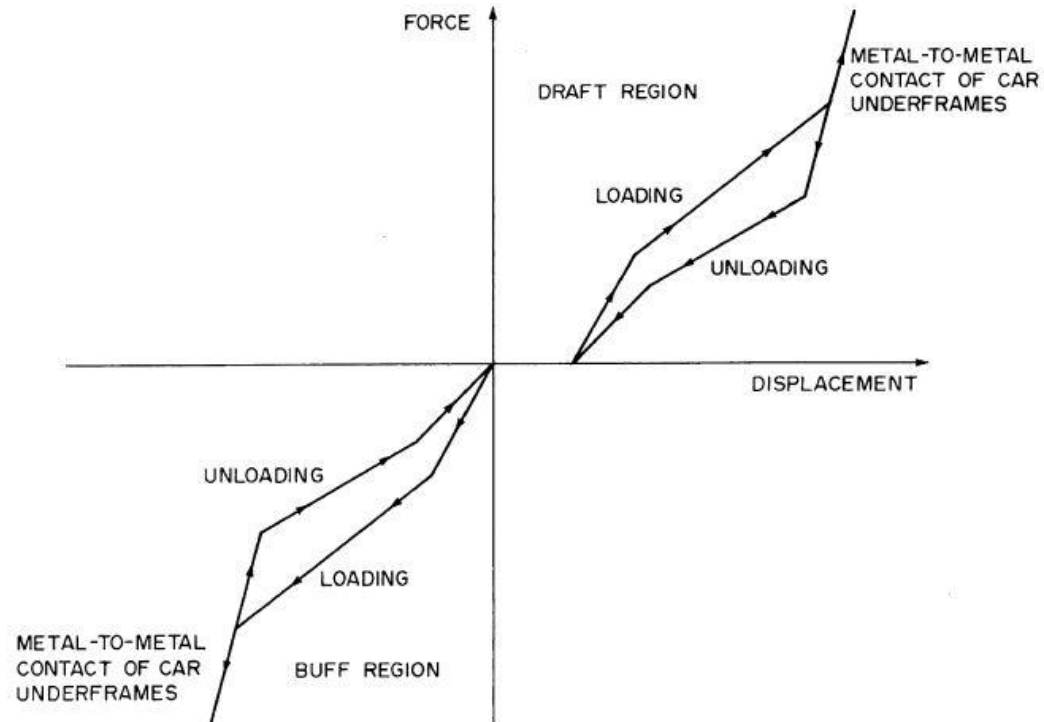
- Draft gears absorb longitudinal shocks during train operations. These devices are generally located on each car in series with the car underframe to transmit the coupler forces.



Draft Gears

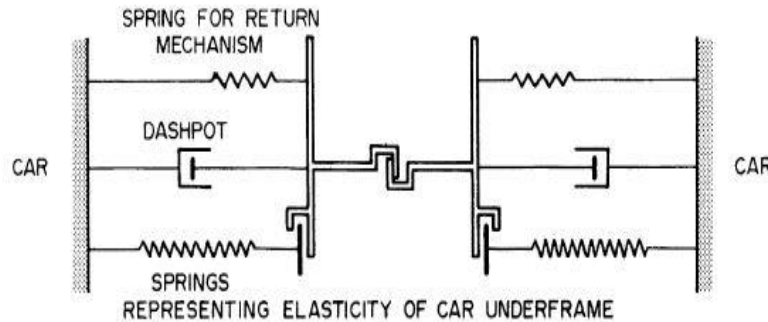


CHARACTERISTICS OF DRAFT GEAR



TRAIN COMPONENTS - CUSHIONING DEVICES

- Cushioning devices, like draft gears, absorb longitudinal shocks during train operations. These devices replace the draft gears in the vehicles.



Cushioning Devices



CREEP

- **Wave action or wave theory:-**

As train is passing under the rolling wheel, the portion under rolling wheel is compressed and depressed slightly due to wheel loads. As wheel moves, this depression also moves and the portion which is under depression previously comes back to its original position. This produces wave action which causes creep in forward direction.

- **Percussion theory:-**

This type of rail creep occurs mainly due to impact of wheel. In this type, when wheel pass over joint, the trailing rail depresses down and wheel gives impact to the end of facing rail which results in creep.

- **Accelerating or starting of a train:-**

At time of acceleration, wheel gives backward thrust which causes creep.

- **De-accelerating or stopping of train, due to application of breaks:-**

If sudden stopping takes place, braking effect tends to push the rail forward and thus causes creep in forward direction.

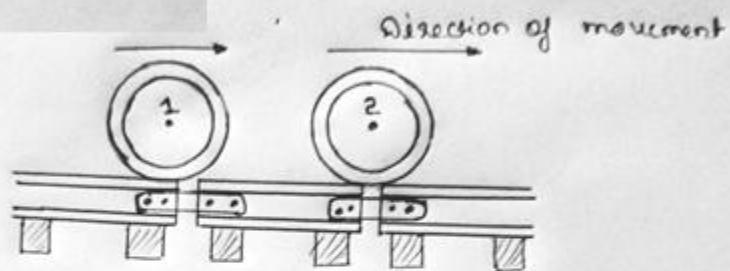
- **Alignment of track:-**

Creep is more on curved portion than straight portion.

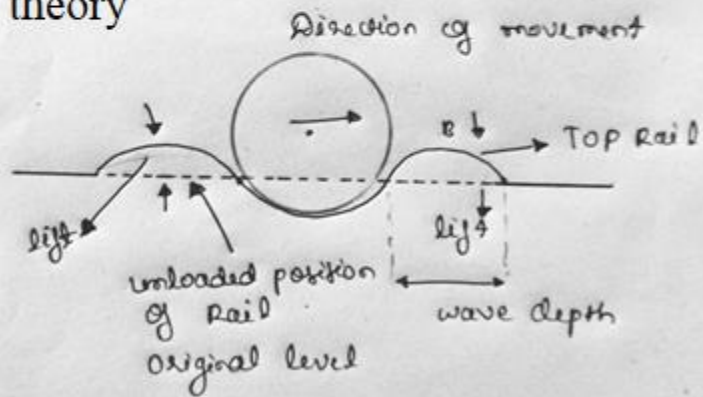


CREEP - THEORIES

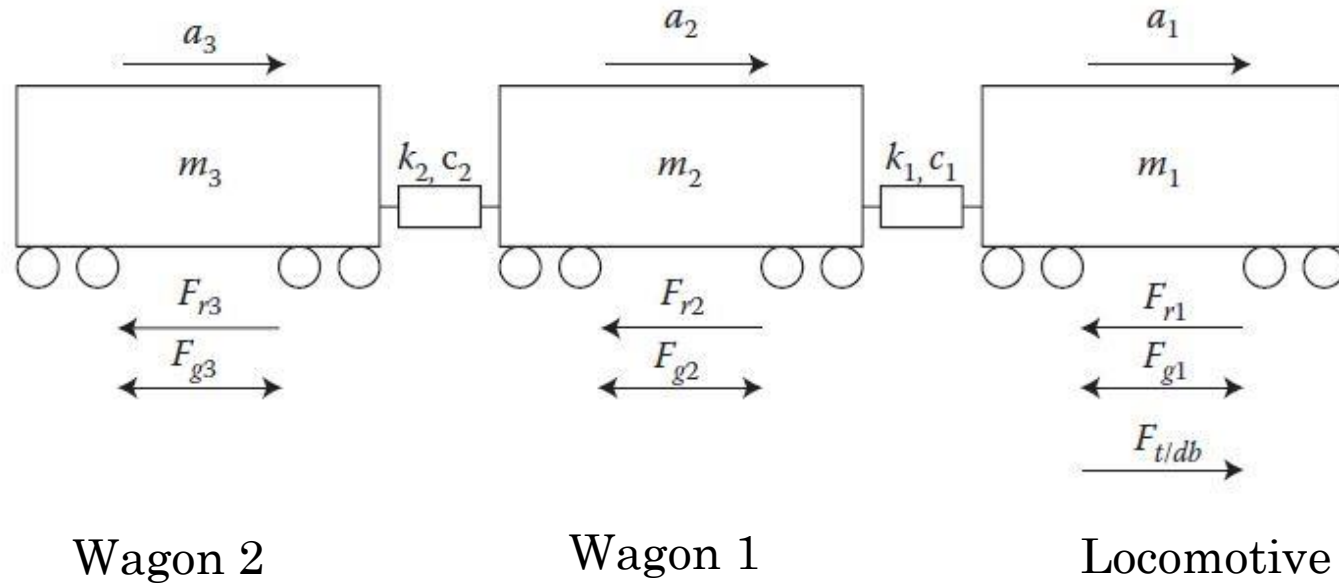
Percussion theory



Wave theory



THREE MASS TRAIN



MATHEMATICAL MODEL

- For the lead vehicle:

$$m_1 a_1 + c_1(v_1 - v_2) + k_1(x_1 - x_2) = F_{t/db1} - F_{r1} - F_{g1}$$

- For the i th vehicle:

$$m_n a_n + c_{n-1}(v_n - v_{n-1}) + k_{n-1}(x_n - x_{n-1}) = F_{t/dbn} - F_{rn} - F_{gn}$$

- For the n th or last vehicle:

$$m_i a_i + c_{i-1}(v_i - v_{i-1}) + c_i(v_i - v_{i+1}) + k_{i-1}(x_i - x_{i-1}) + k_i(x_i - x_{i+1}) = F_{t/dbi} - F_{ri} - F_{gi}$$



MATHEMATICAL MODEL FOR THREE MASS TRAIN

Equations of motion in global coordinate system

$$m_1 a_1 + c_1(v_1 - v_2) + k_1(x_1 - x_2) = F_{t/db} - F_{r1} - F_{g1}$$

$$m_2 a_2 + c_1(v_2 - v_1) + c_2(v_2 - v_3) + k_1(x_2 - x_1) + k_2(x_2 - x_3) = F_{r2} - F_{g2}$$

$$m_3 a_3 + c_2(v_3 - v_2) + k_2(x_3 - x_2) = -F_{r3} - F_{g3}$$

Resistance force F_r

$$F_r = F_{pr} + F_{cr} + F_b$$

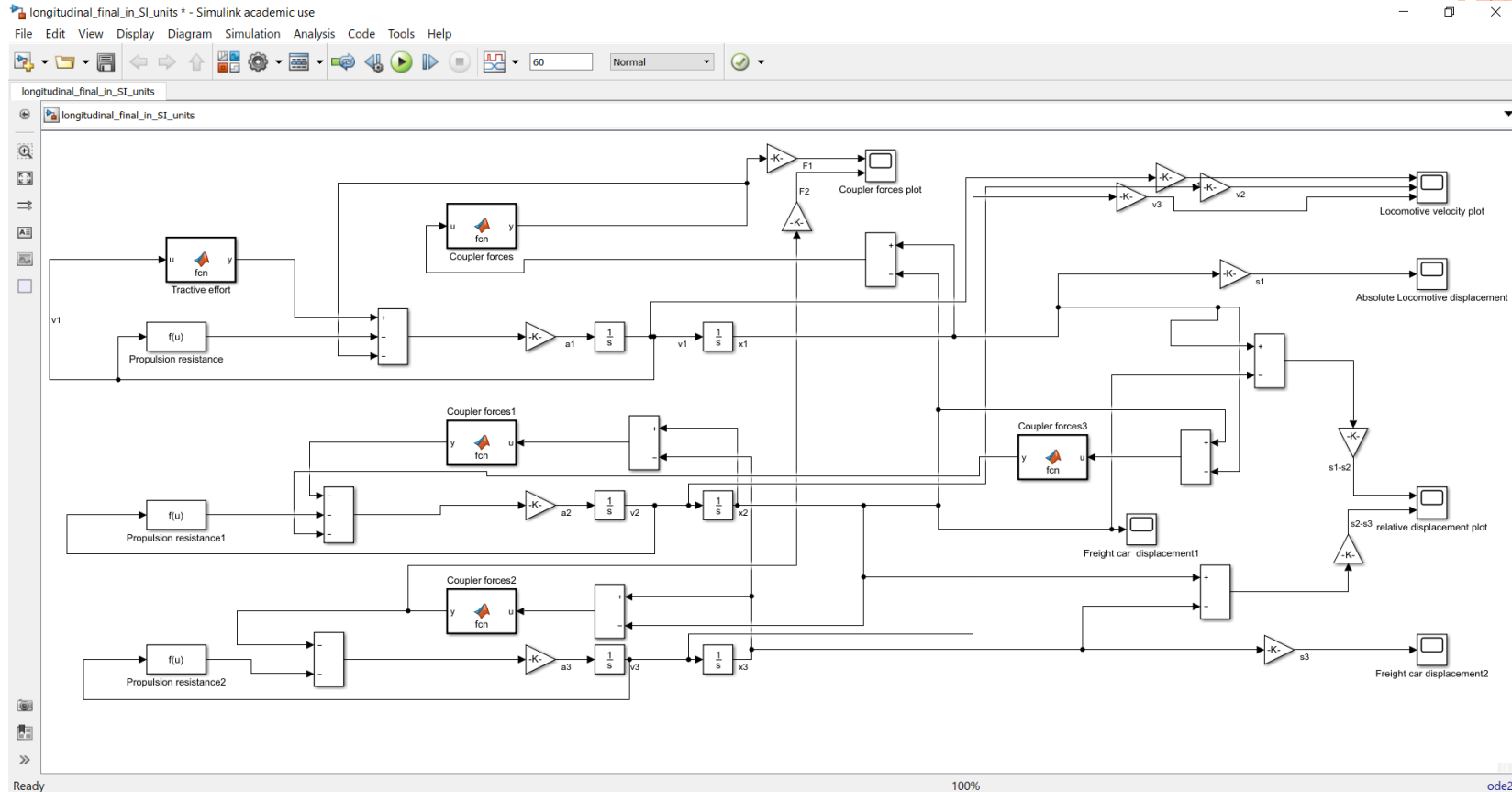
F_{pr} = Propulsion resistance

F_{cr} = Curving resistance

F_b = Braking resistance



SIMULINK MODEL



Locomotive

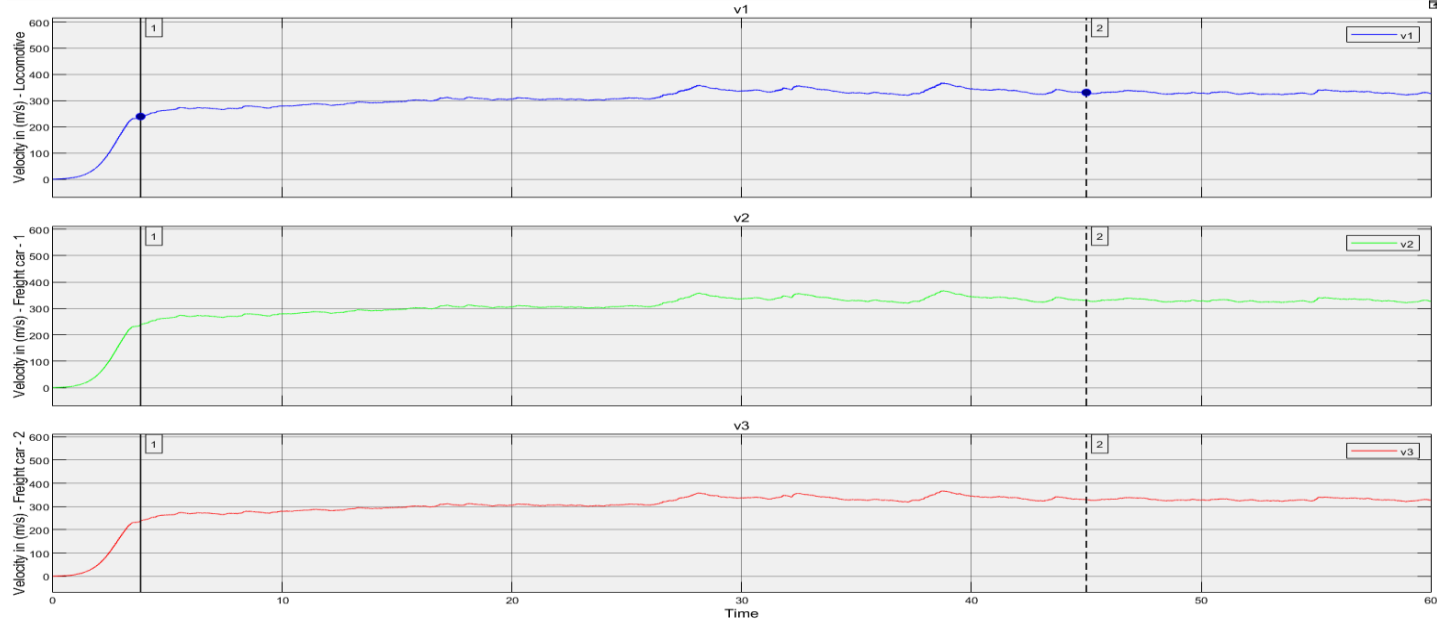
Wagon 1

Wagon 2

RESULTS

Locomotive velocity plot

File Tools View Simulation Help



Ready

Sample based T=60.000

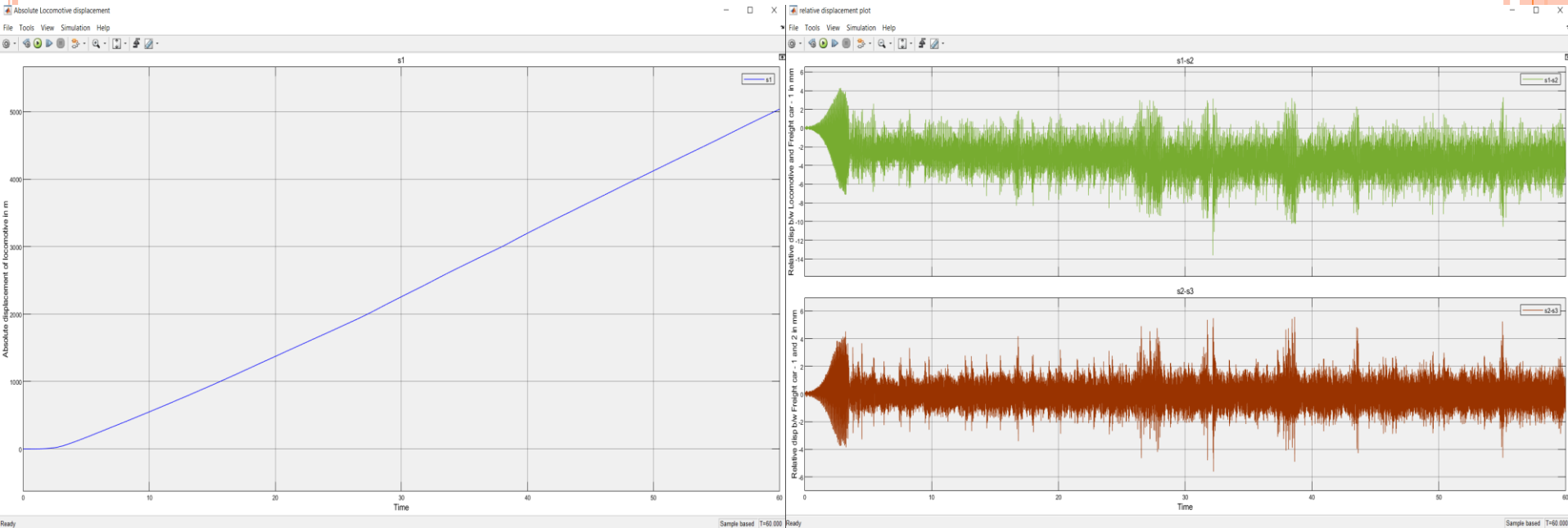
Trace Selection			
v1			
Cursor Measurements			
Settings			
Measurements			
	Time	Value	
1	3.817	2.392e+02	
2	45.000	3.311e+02	
ΔT	41.183 s	ΔY	9.187e+01
1 / ΔT		24.282 mHz	
ΔY / ΔT		2.231 (/s)	

Trace Selection			
v2			
Cursor Measurements			
Settings			
Measurements			
	Time	Value	
1	3.817	2.380e+02	
2	45.000	3.302e+02	
ΔT	41.183 s	ΔY	9.227e+01
1 / ΔT		24.282 mHz	
ΔY / ΔT		2.240 (/s)	

Trace Selection			
v3			
Cursor Measurements			
Settings			
Measurements			
	Time	Value	
1	3.817	2.380e+02	
2	45.000	3.306e+02	
ΔT	41.183 s	ΔY	9.262e+01
1 / ΔT		24.282 mHz	
ΔY / ΔT		2.249 (/s)	

Velocity v/s time

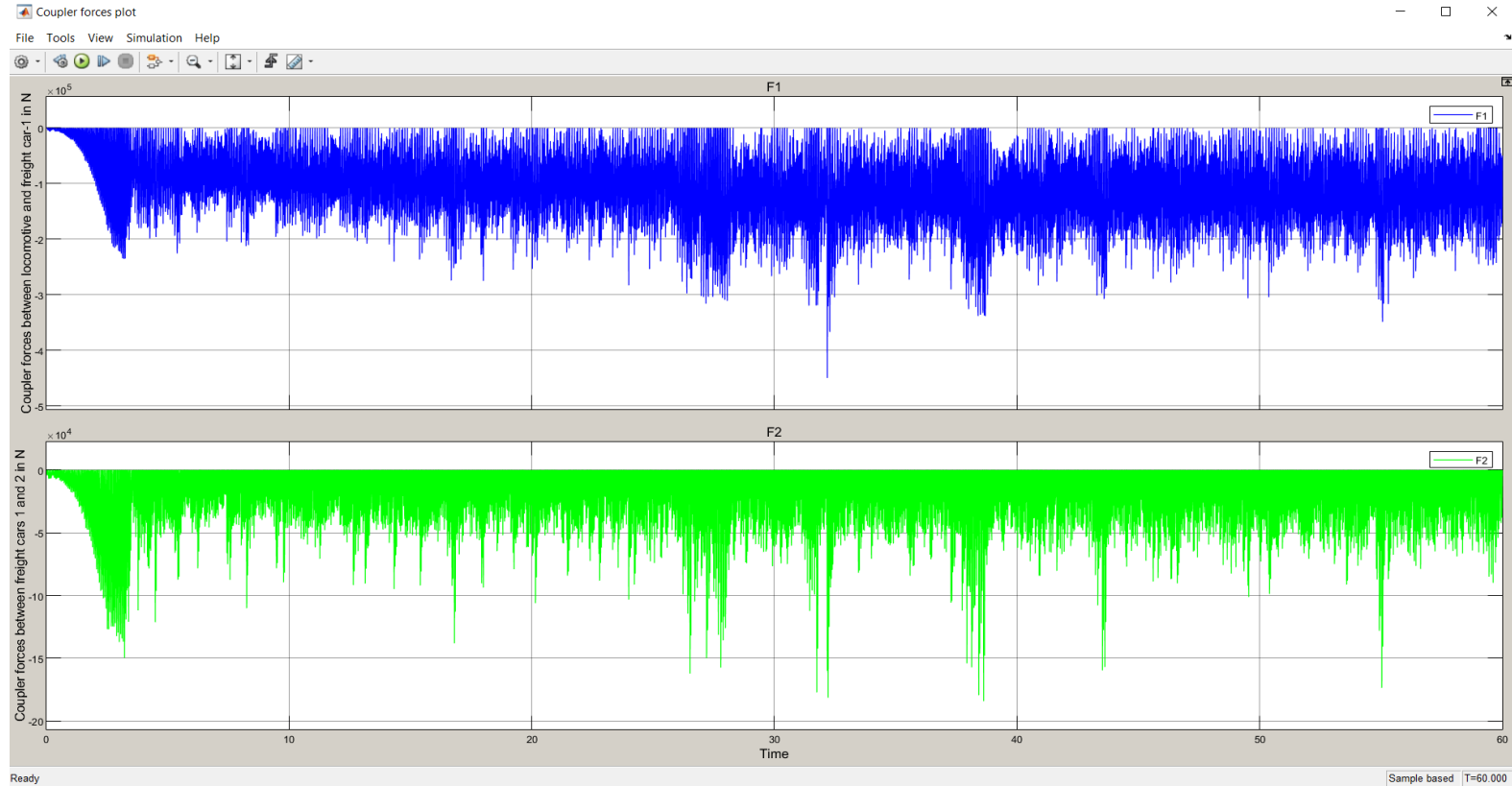
RESULTS (CONTD.)



Absolute displacement v/s time

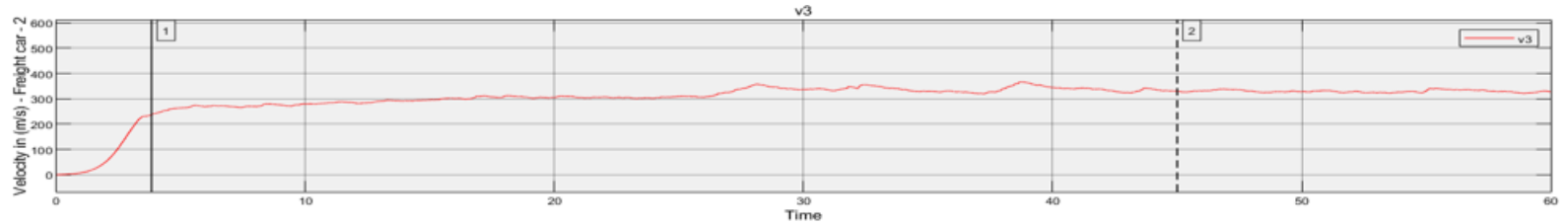
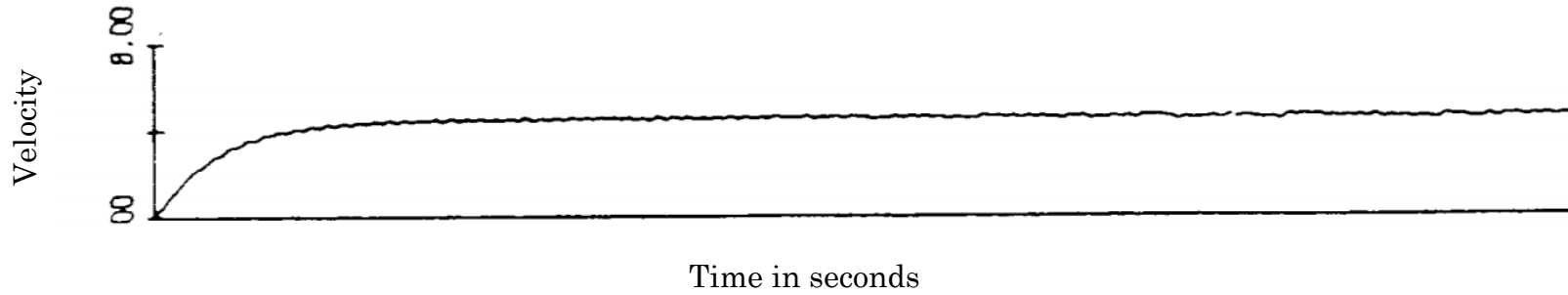
Relative displacement v/s time

RESULTS (CONTD.)

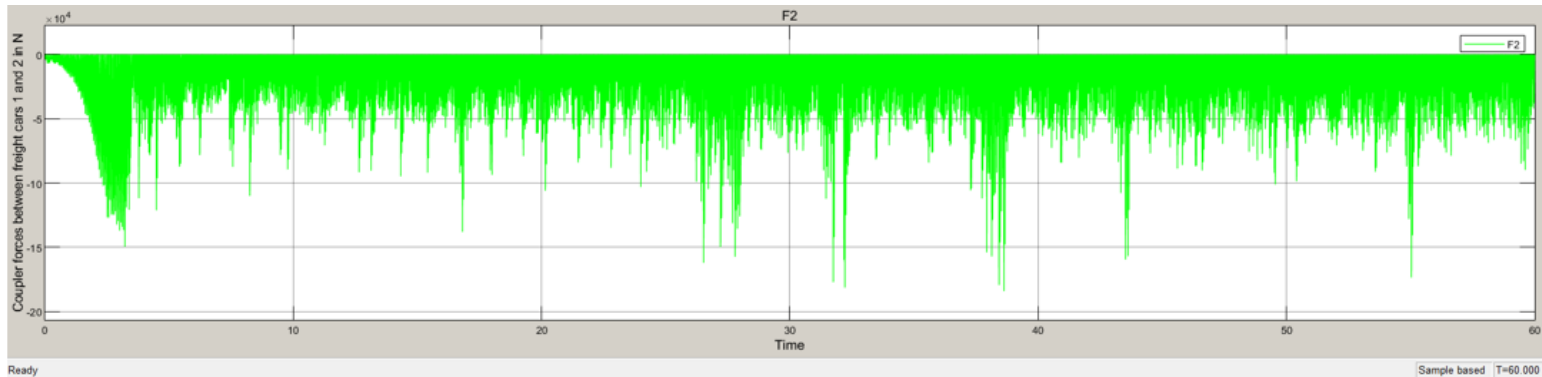
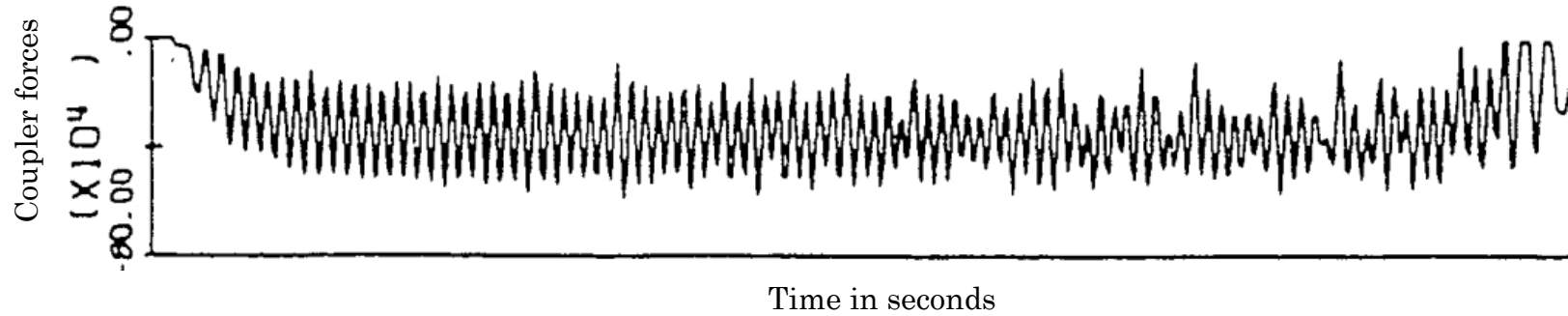


Coupler forces

RESULTS VALIDATIONS



RESULTS VALIDATIONS



LATERAL STABILITY

Mathematical model

$$m \ddot{y} + \frac{2f_{11}}{V} \left[\dot{y} + r_0 \frac{\lambda}{a} \dot{y} - V\psi \right] + \frac{2f_{12}}{V} \dot{\psi} + W_A \frac{\lambda}{a} y = F_{sy},$$

$$I_{wx} \ddot{\psi} + I_{wy} \frac{V \lambda}{r_0 a} \dot{y} + \frac{2af_{33}\lambda}{r_0} y - \frac{2f_{12}}{V} \left(\dot{y} + r_0 \frac{\lambda}{a} \dot{y} - V\psi \right) + 2a^2 f_{33} \frac{\dot{\psi}}{V} - aW_A \lambda \psi + 2f_{22} \frac{\dot{\psi}}{V} = M_{sz}.$$

$f_{11}, f_{12}, f_{33}, f_{22}$ are linear creep coefficients

V – Axle speed

W_A – Axle load

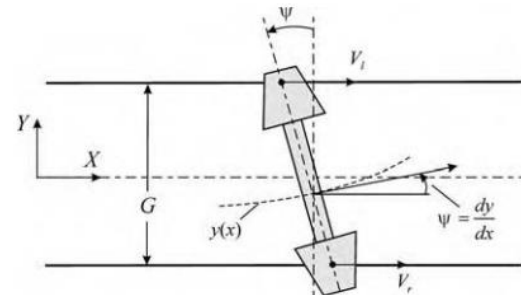
Ψ – Yaw

F_{sy} - External lateral force

M_{sz} - External yaw moment

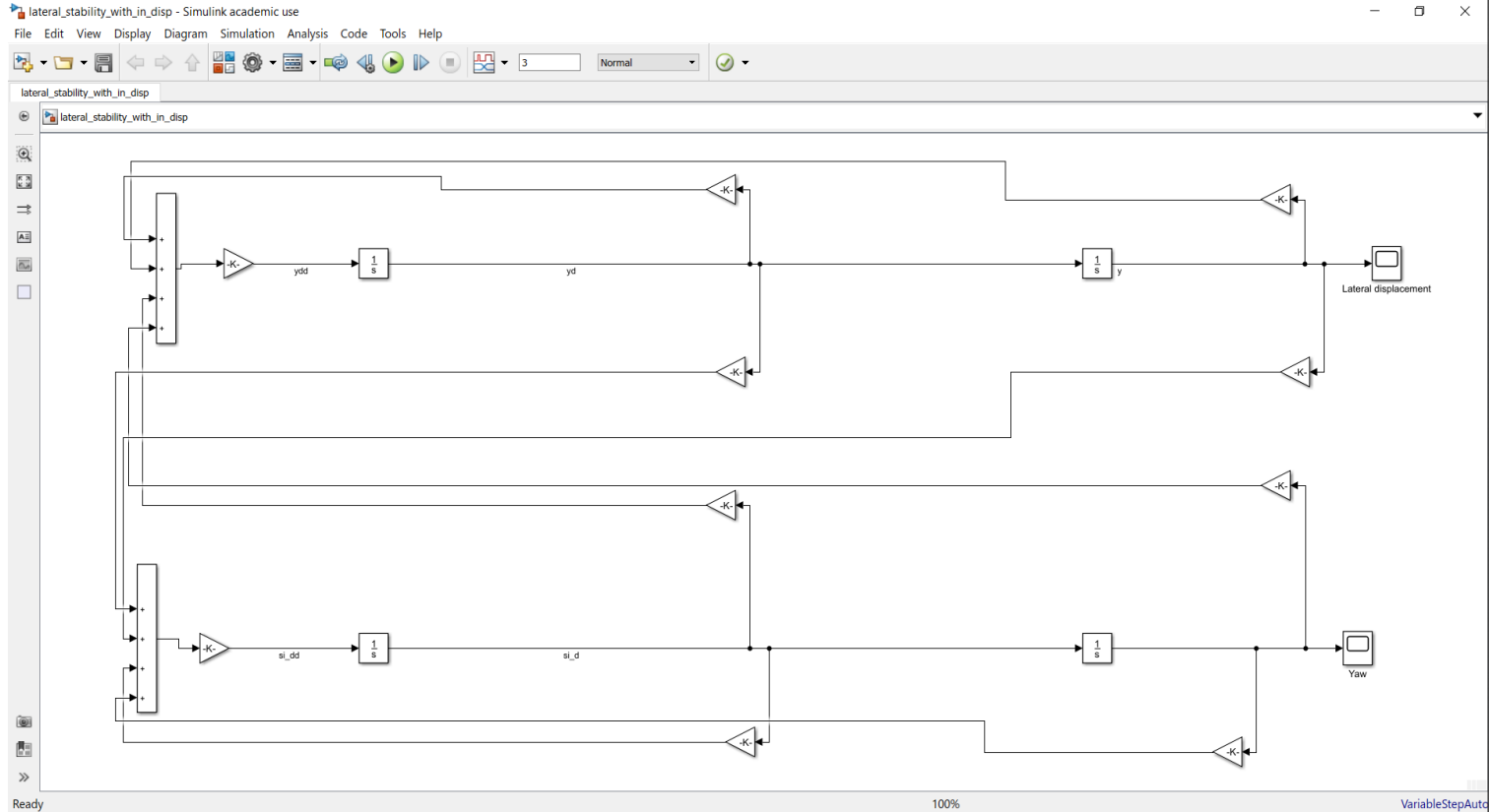
λ – Conicity angle

a - Half of the distance between contact points on two rails



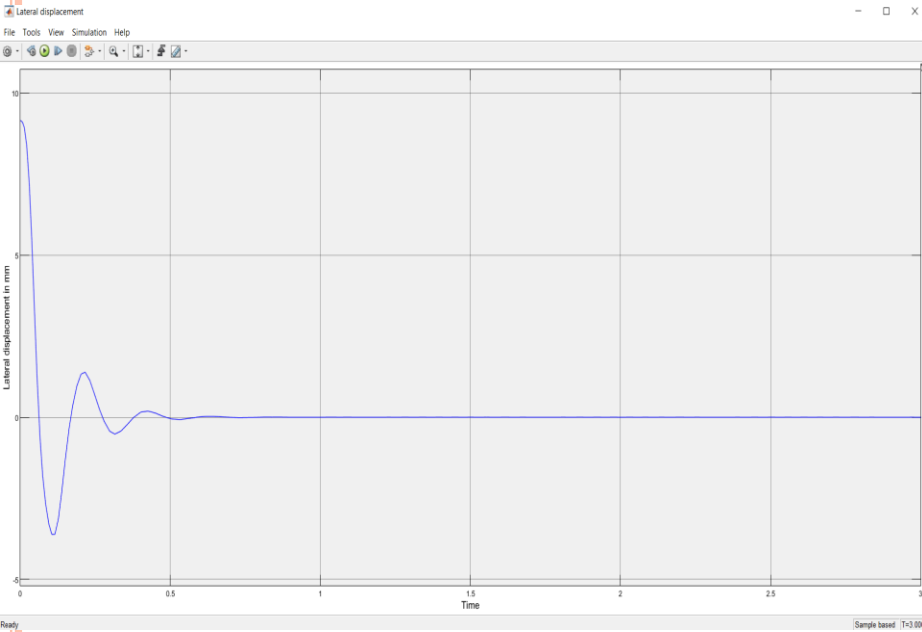
Wheel set hunting motion

SIMULINK MODEL

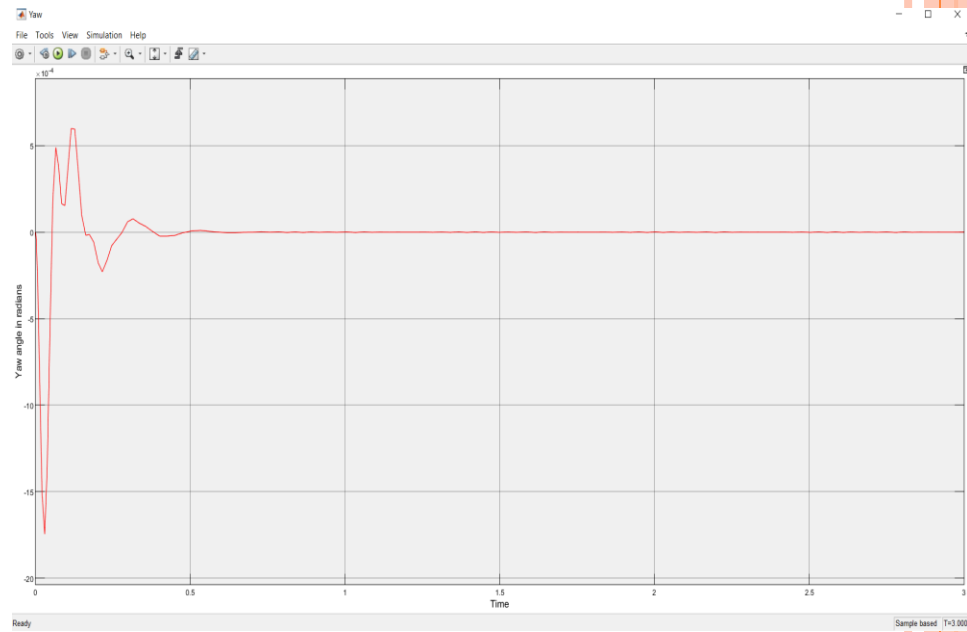


Initial displacement model

RESULTS



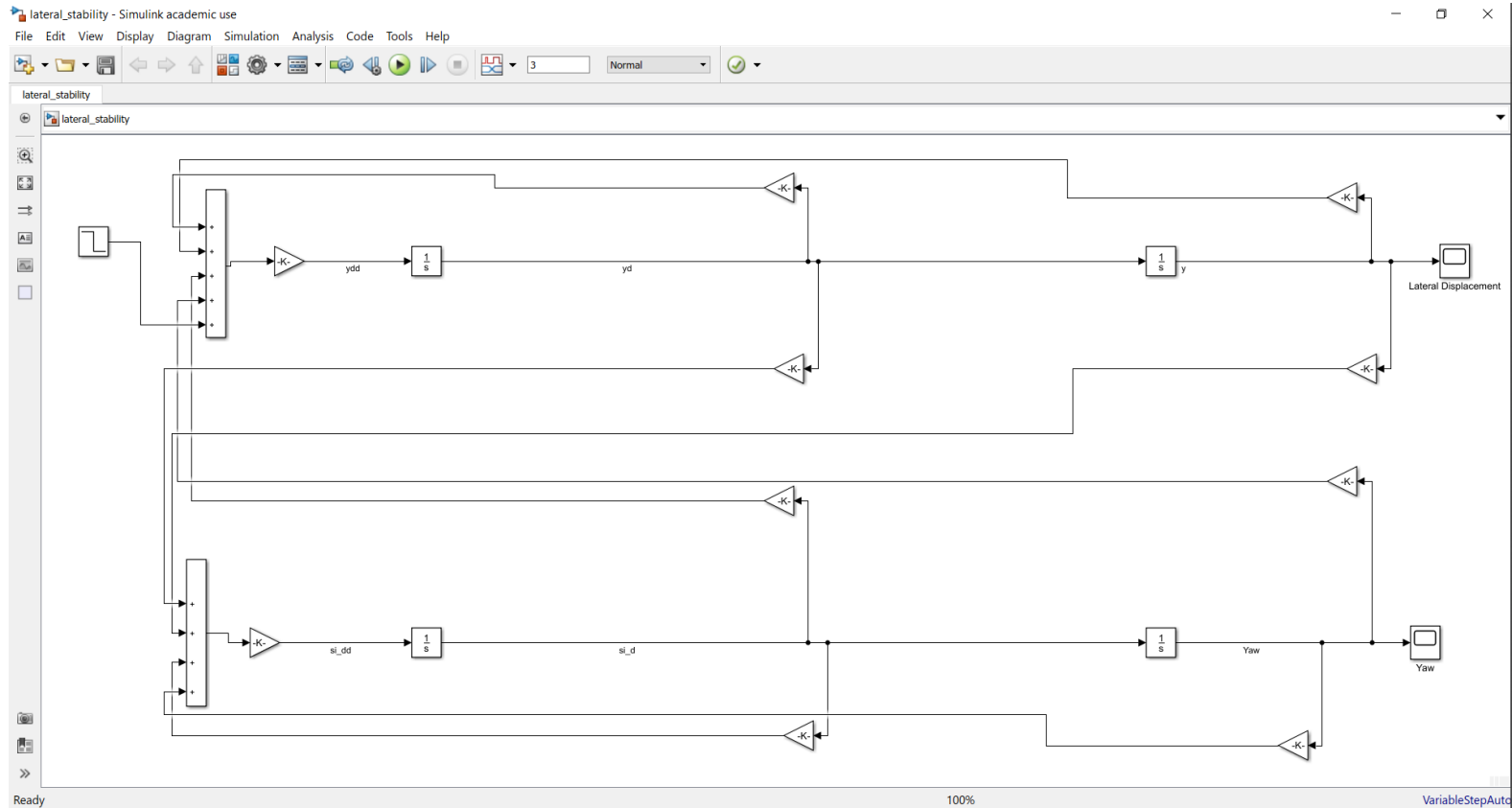
Lateral displacement v/s
time



Yaw v/s time



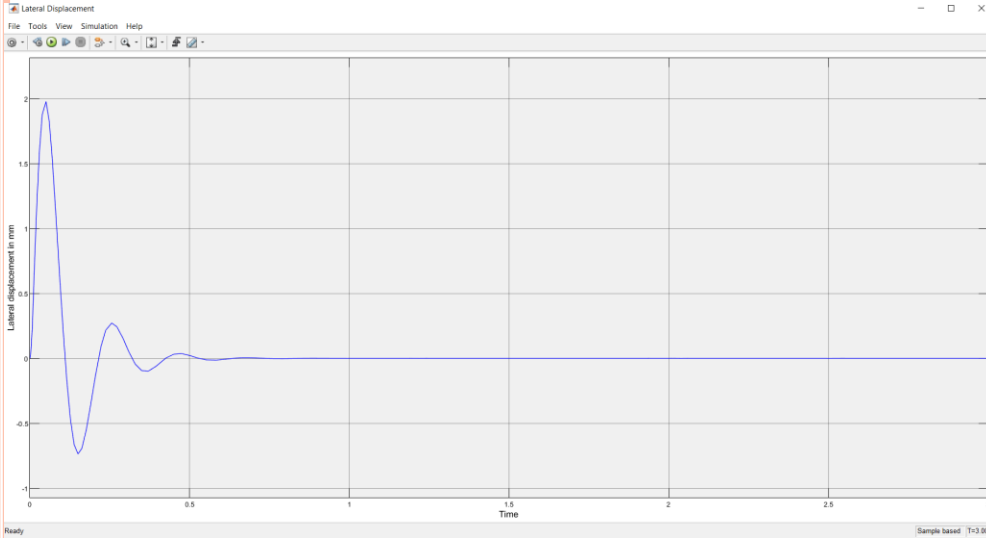
Simulink model



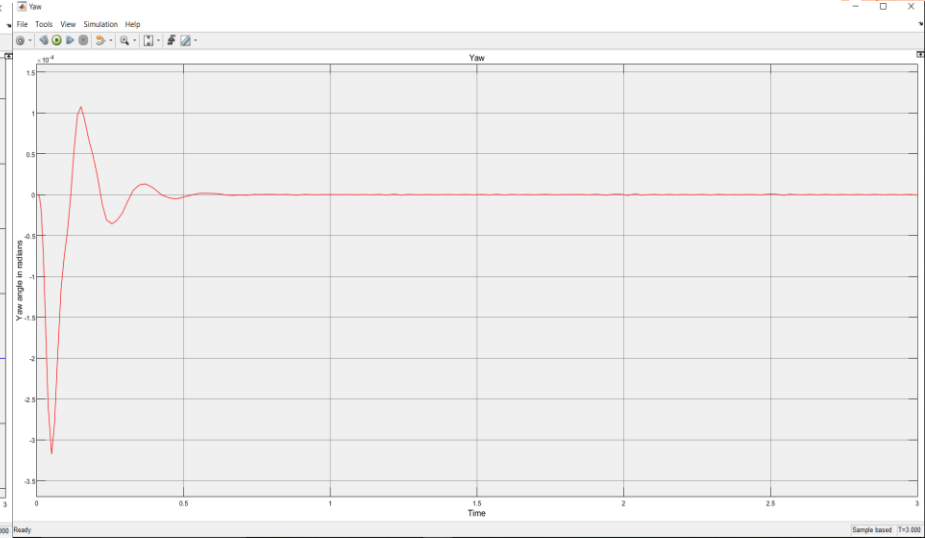
INITIAL FORCE MODEL



RESULTS



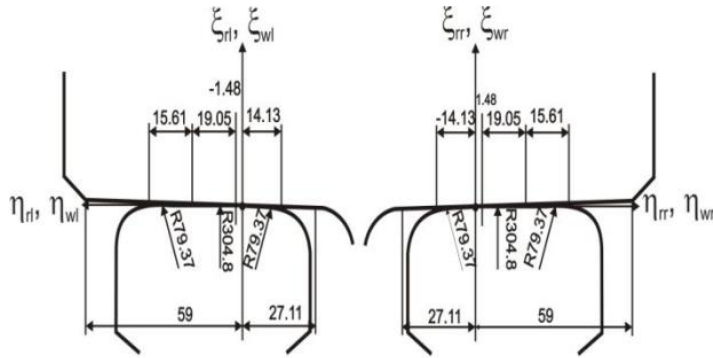
Lateral displacement v/s
time



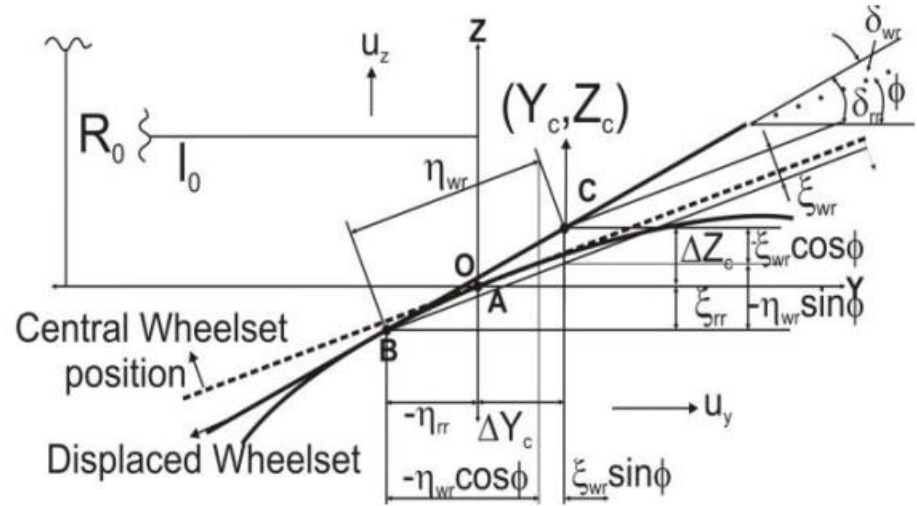
Yaw v/s time



RAIL WHEEL CONTACT GEOMETRY



Wheel rail contact geometry



Right wheel rail geometry

RAIL WHEEL CONTACT GEOMETRY ANALYSIS

Hertzian theory

Penetration depth

$$d = r \left(\left(\frac{3}{2} F_n \frac{1 - \nu^2}{E} \right)^2 (A + B) \right)^{1/3}$$

$$A = \frac{1}{2r_{wy}}$$

$$B = \frac{1}{2} \left(\frac{1}{R_{wx}} + \frac{1}{R_{rx}} \right)$$

R_{wy} the rolling radius of the wheel

R_{wx} the local radius of the wheel profile in lateral direction

R_{rx} the local radius of the rail profile in lateral direction.

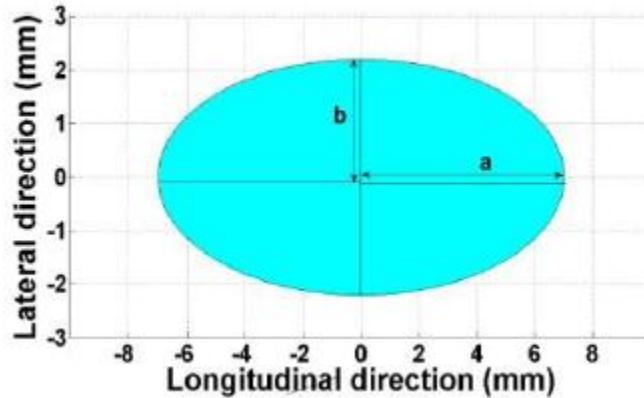
$$R_{rx} = \frac{(1 + z_r'^2)^{3/2}}{z_r''}$$



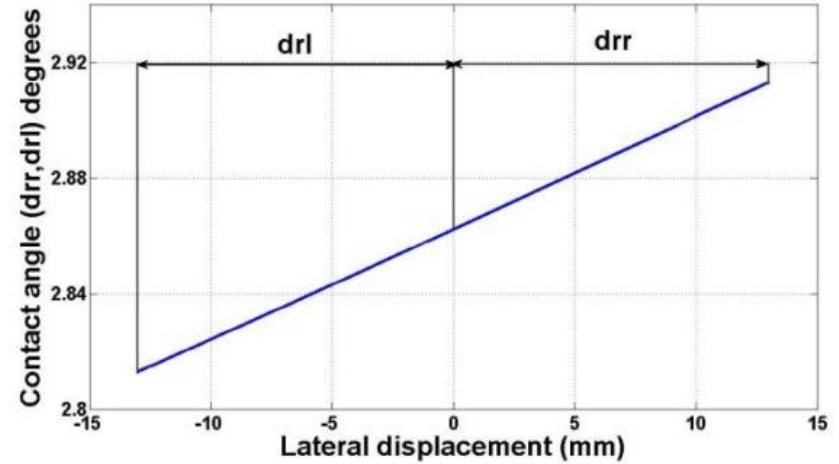
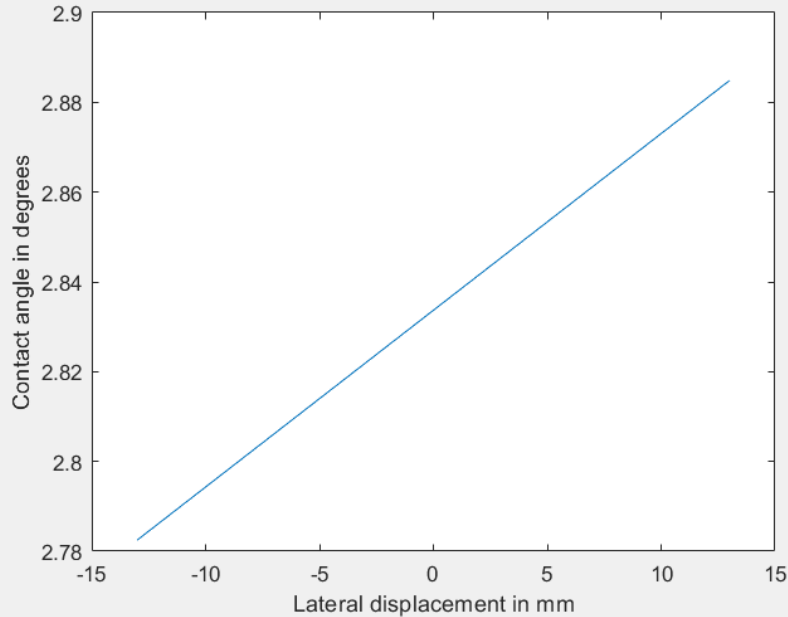
CONTACT GEOMETRY

$$a = m \left(\frac{3}{2} F_n \frac{1 - \nu^2}{E} \frac{1}{A + B} \right)^{1/3}$$

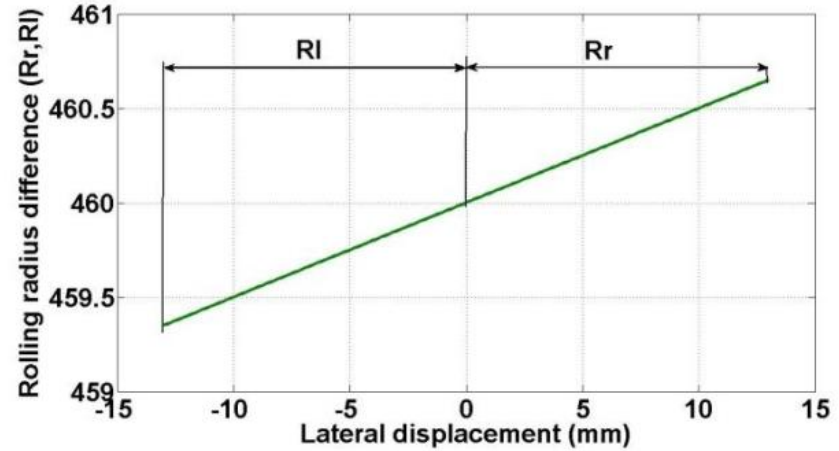
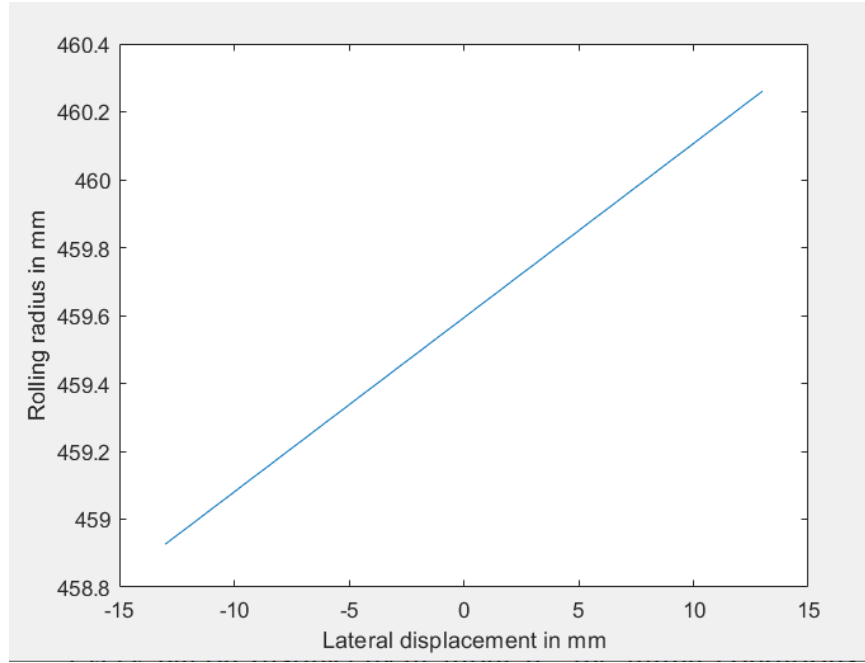
$$b = n \left(\frac{3}{2} F_n \frac{1 - \nu^2}{E} \frac{1}{A + B} \right)^{1/3}$$



RESULTS VALIDATION ON RAIL WHEEL CONTACT GEOMETRY



RESULTS VALIDATION ON RAIL WHEEL CONTACT GEOMETRY



CONCLUSION

- Longitudinal dynamics analysis has been done to determine the coupler forces and longitudinal motion of a train in over-the-rail operations.
- The lateral analysis was done to ensure that our model won't become unstable on the track as our linear wheelset velocity increases due to increased lateral oscillations.



FUTURE SCOPE

- For Longitudinal dynamics we can further consider the coupling of lateral and vertical dynamics affecting the longitudinal motion.
- In lateral dynamics we can consider the influence conformity on wheel rail rolling contact mechanics to predict the actual contact area, which can then be used in modified Kalker theory to predict creep forces.



REFERENCES

- i. A Novel Approach To Modelling And Simulation Of The Dynamic Behaviour Of The Wheel-Rail Interface, Arthur Anyakwo, Proceedings Of The 17th International Conference On Automation & Computing
- ii. Dynamics Of Railway Vehicle Systems, Vijay K. Garg, Rao V. Dukkipati
- iii. Handbook Of Railway Vehicle Dynamics, Edited By Simon Iwnicki
- iv. Method Of Analysis For Determining The Coupler Forces And Longitudinal Motion Of A Long Freight, G. C. Martin And W.H. Hay
- v. Design And Simulation of Rail Vehicles, Colin Cole Et.. Al, Edited By Vladimir V. Vantsevich

Software used:

- 1. Matlab Simulink 2018b, Academic version
- 2. Catia V5, Student version

