The Running Behaviour of an Elastic Wheelset

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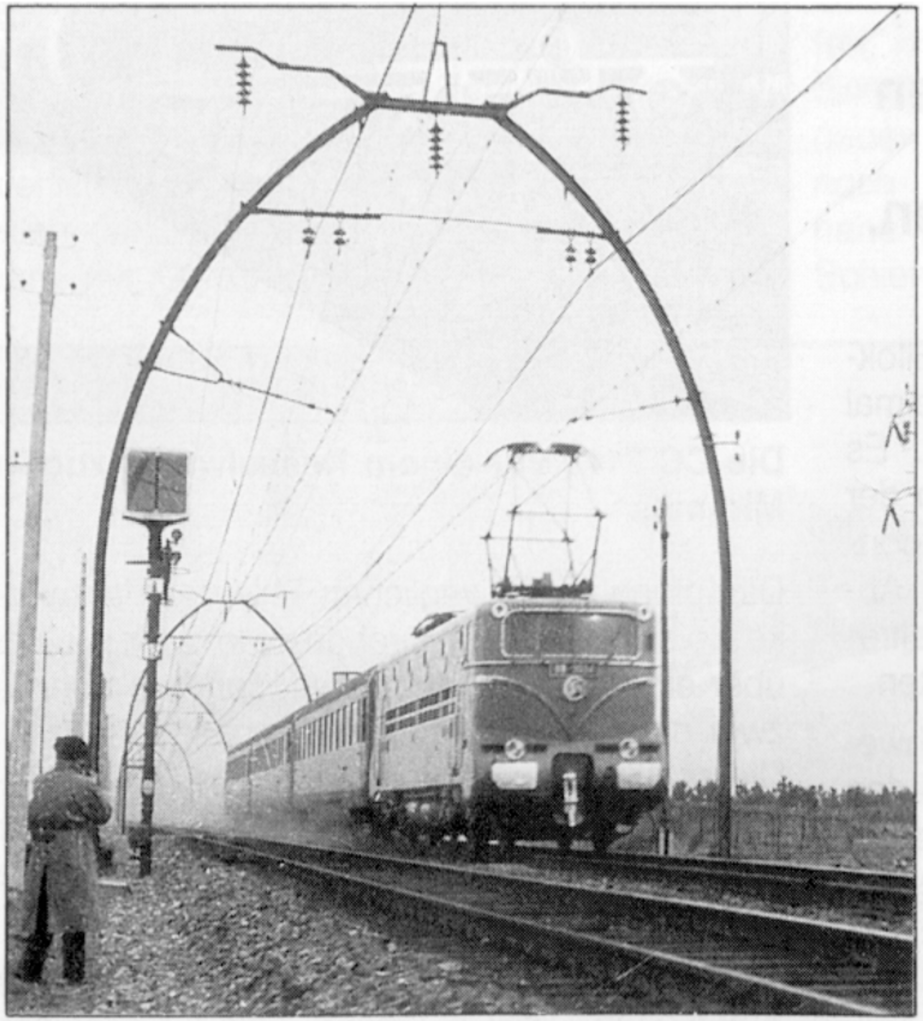
Outline

- Introduction
- Modelling of the vehicle
  - Integration of the rotating elastic wheelsets
  - Structural dynamics of the wheelsets
- Modelling of the track
  - Structure of a track with discrete sleepers
  - Structural dynamics of the rails
- Simulation results: The influence of the structural elasticities
- Concluding remarks

Vehicle-track interaction

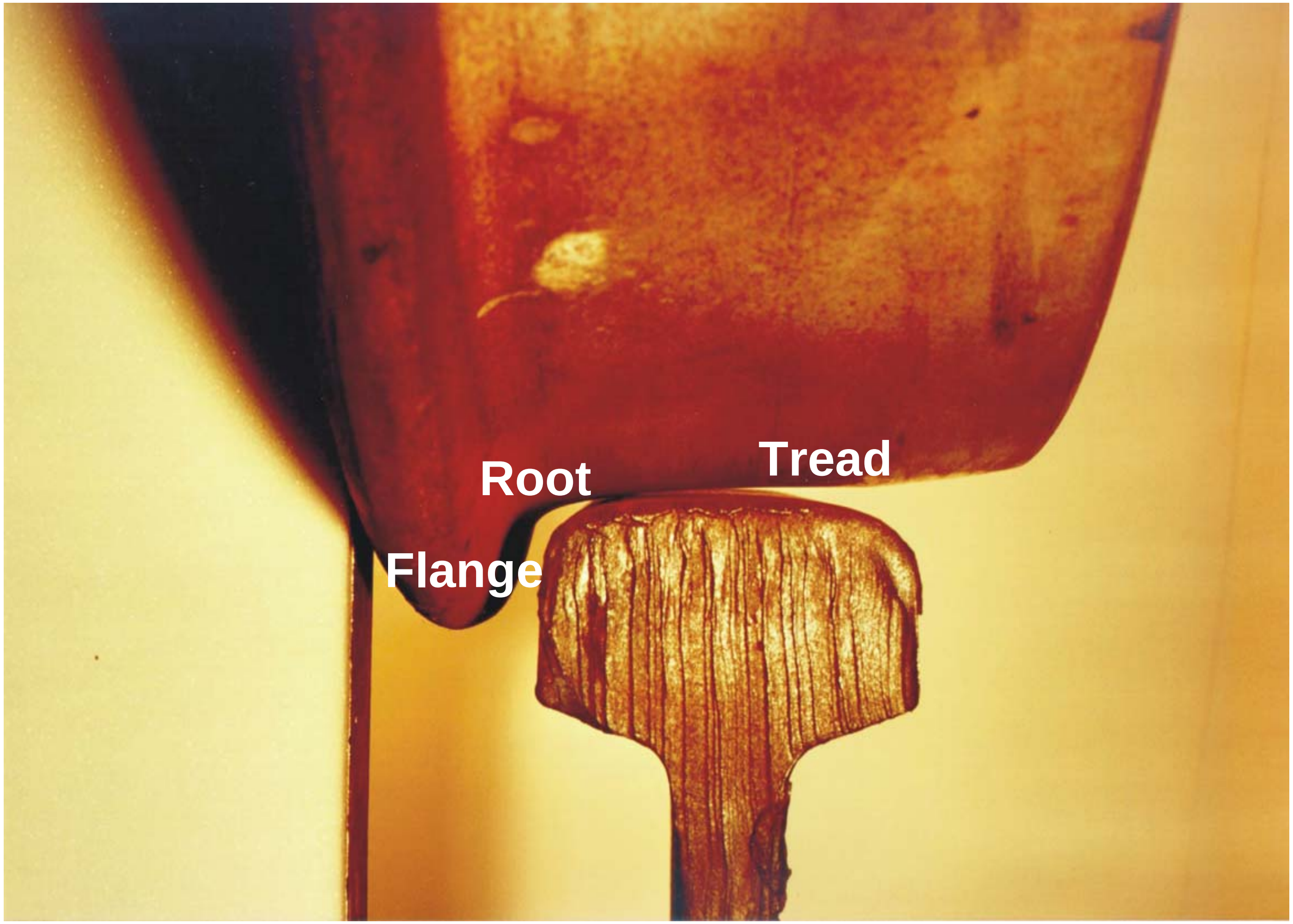
World speed record, 1955, 331 km/h, near Bordeaux



Source: eisenbahn-magazin 3/95 / SNCF / Sammlung Messerschmidt

Source: eisenbahn-magazin 3/95 / La Vie du Rail / Sammlung Hughes

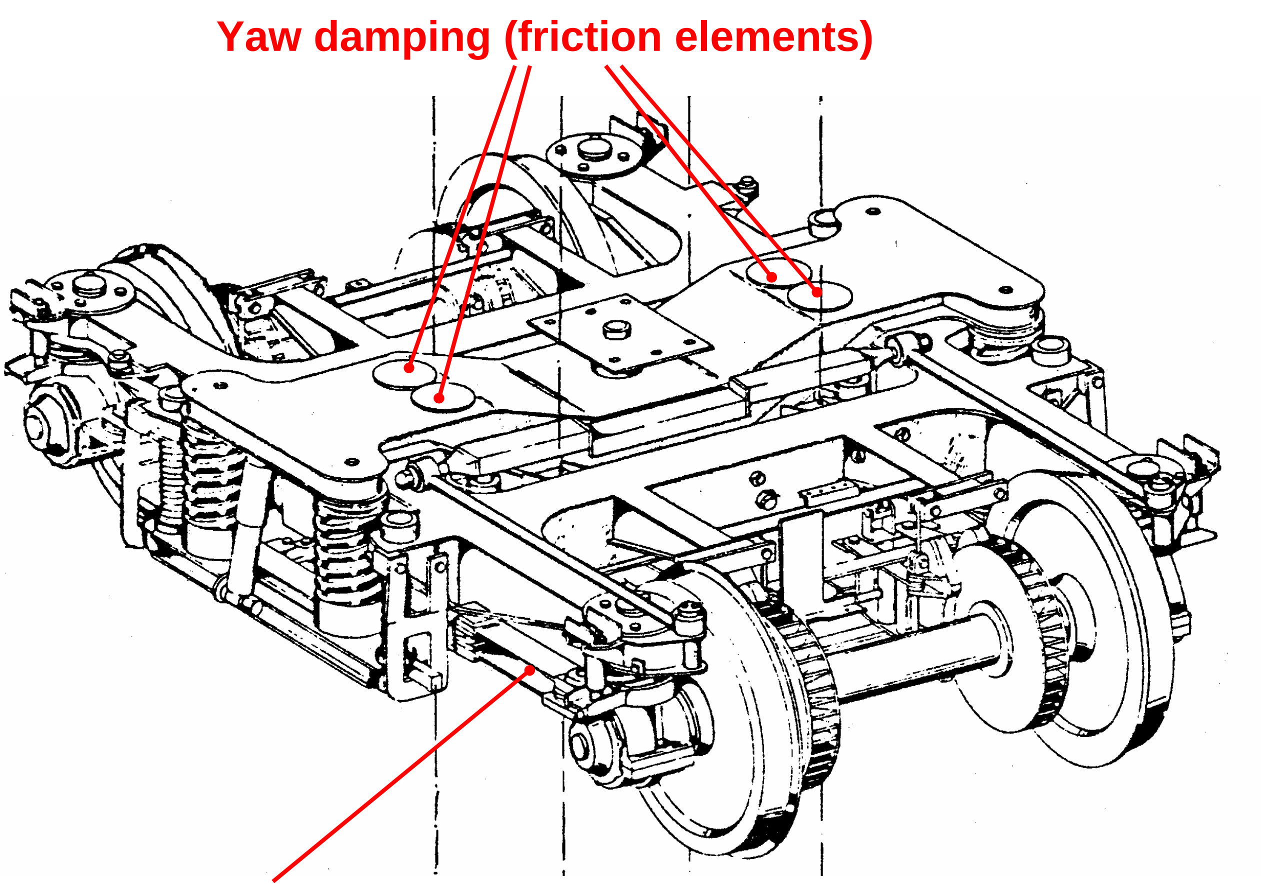
Real wheel-rail contact



Source: Institute for Railway Vehicles, University of Hannover

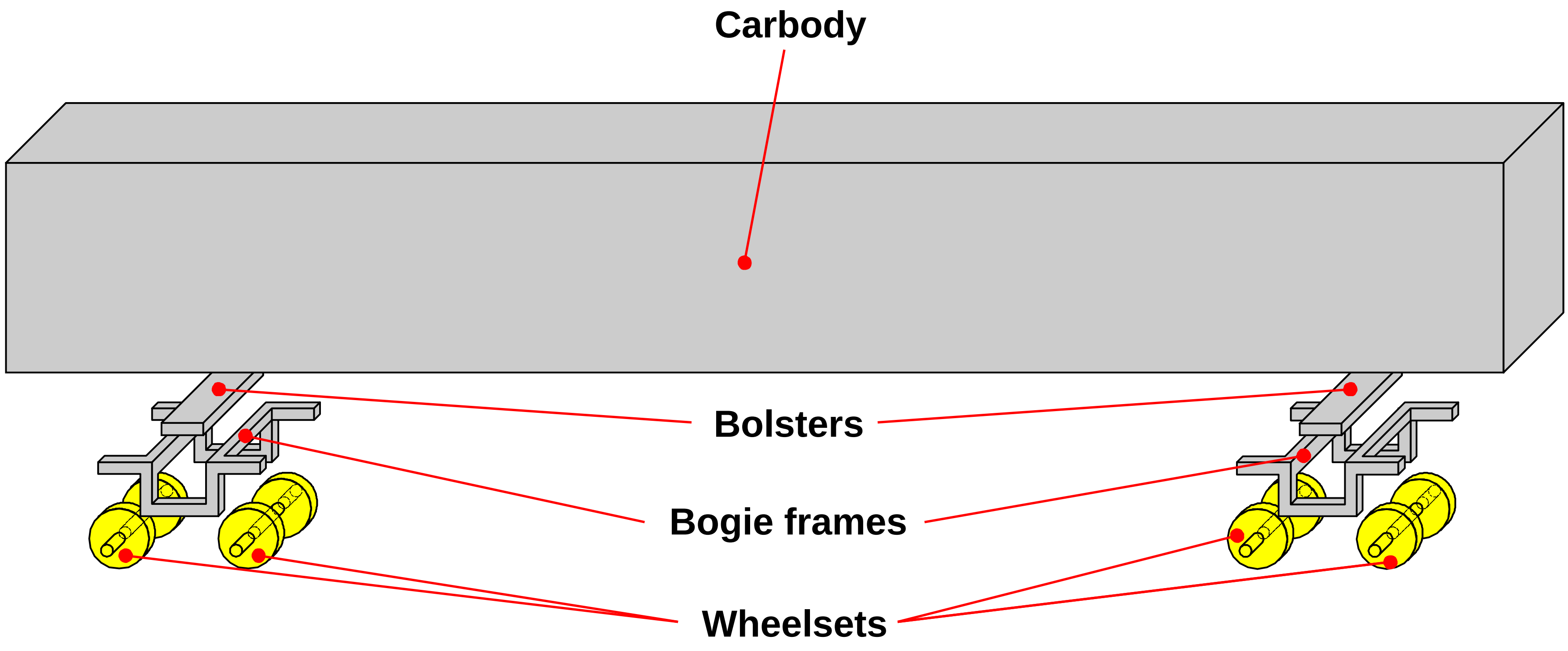
Real system

Bogie type MD (Minden-Deutz) 522



Source: G. Voß, Lecture „Konstruktion der Schienenfahrzeuge“, University of Hannover

Structure of the vehicle



- **Wheelsets: Elastic bodies with 6 rigid body motions (DoF) + DoFs for deformation**
- **Carbody, bogie frames: Rigid bodies, 6 DoF**
- **Bolsters: Rigid bodies, 1 DoF (yaw motion relative to carbody)**
- **Coupling of the bodies by linear spring/damper-elements, exception: yaw damping by dry friction between carbody and bolsters**

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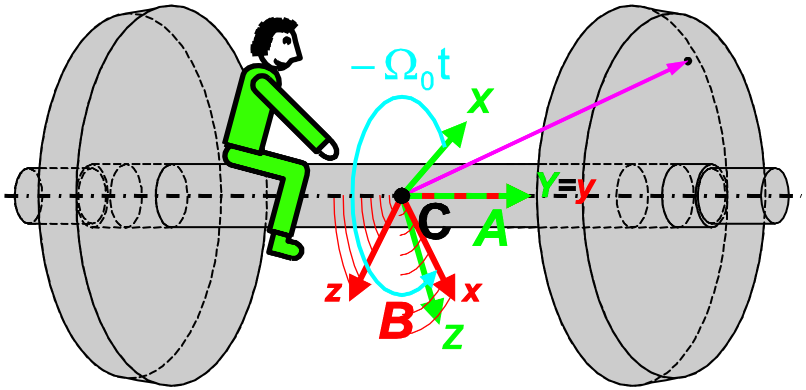
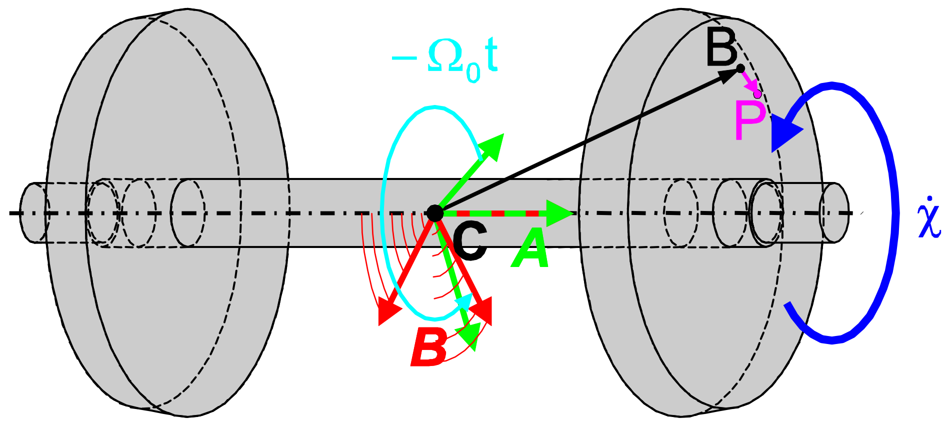
Integration of the rotating elastic wheelsets

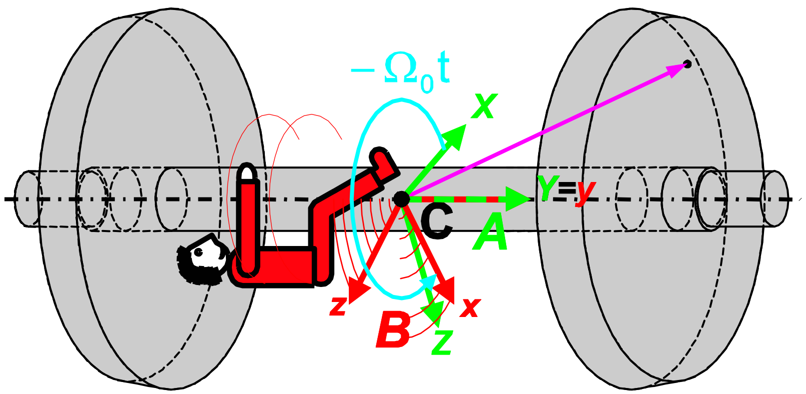
Eulerian approach



Arbitrary Lagrangian-Eulerian approach (ALE)



Lagrangian approach



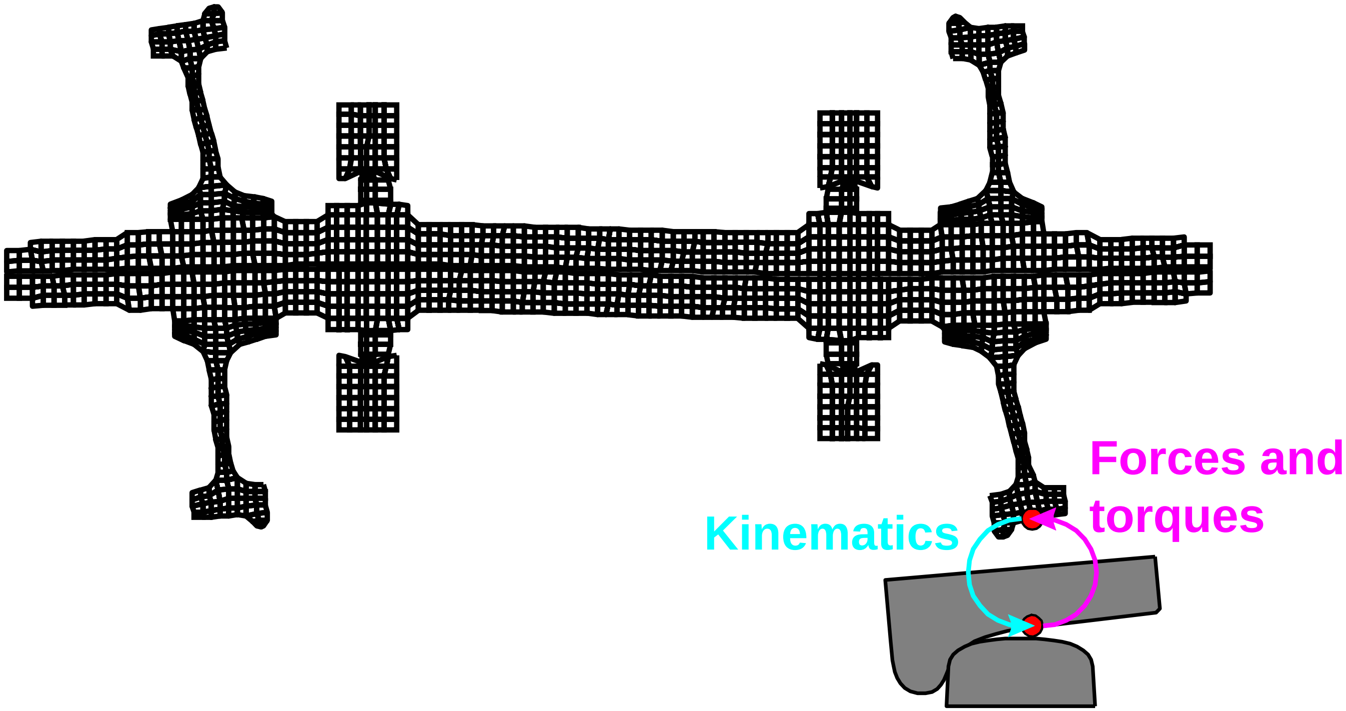
Modal synthesis in the non-overturning system *A* :

$$\mathbf{r}^{A}_{CP} = \left[r\sin\theta \quad y \quad r\cos\theta \right]^{T} + \sum_{i=1}^{n} \mathbf{W}_i(\mathbf{r},\theta,\mathbf{y})\, q_i(t)$$

Time derivative:

$$\frac{d\mathbf{r}^{A}_{CP}}{dt} = \frac{\partial \mathbf{r}^{A}_{CP}}{\partial t} + \frac{\partial \mathbf{r}^{A}_{CP}}{\partial \theta}\,\dot{\chi}$$

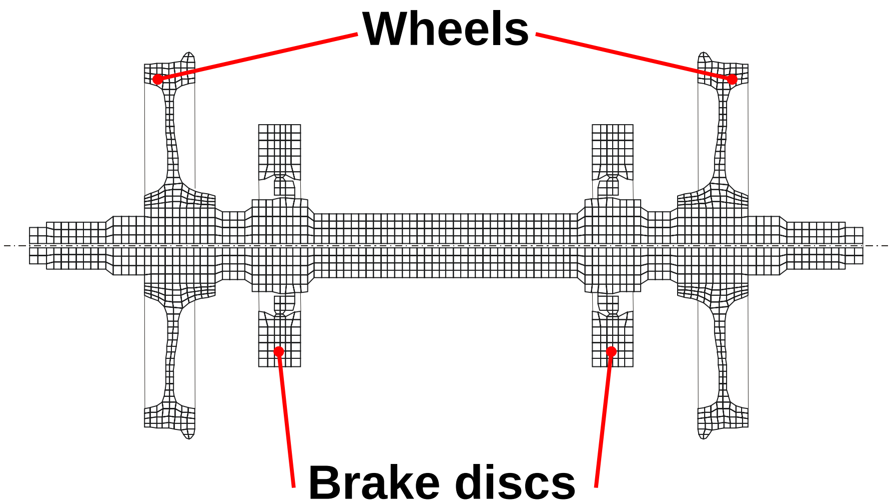
Coupling of the elastic wheelset and the contact



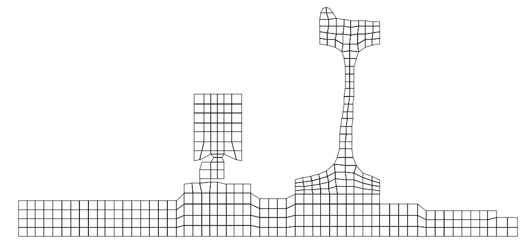
- Application of the kinematics from the wheelset on the contact at the wheel node
- Application of the forces from the contact on the wheelset at the wheel node
- Consideration of the shifting of the actual contact by additional torques

Finite-Element model of the wheelset

Complete structure



Reduction by using symmetries



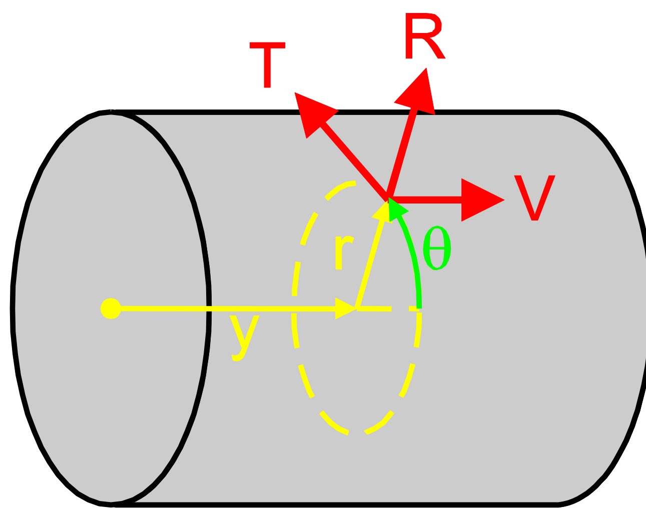
490 nodes, 1465 or 1460 DoFs

Semianalytic solution of Navier's equations for a rotational symmetric structure

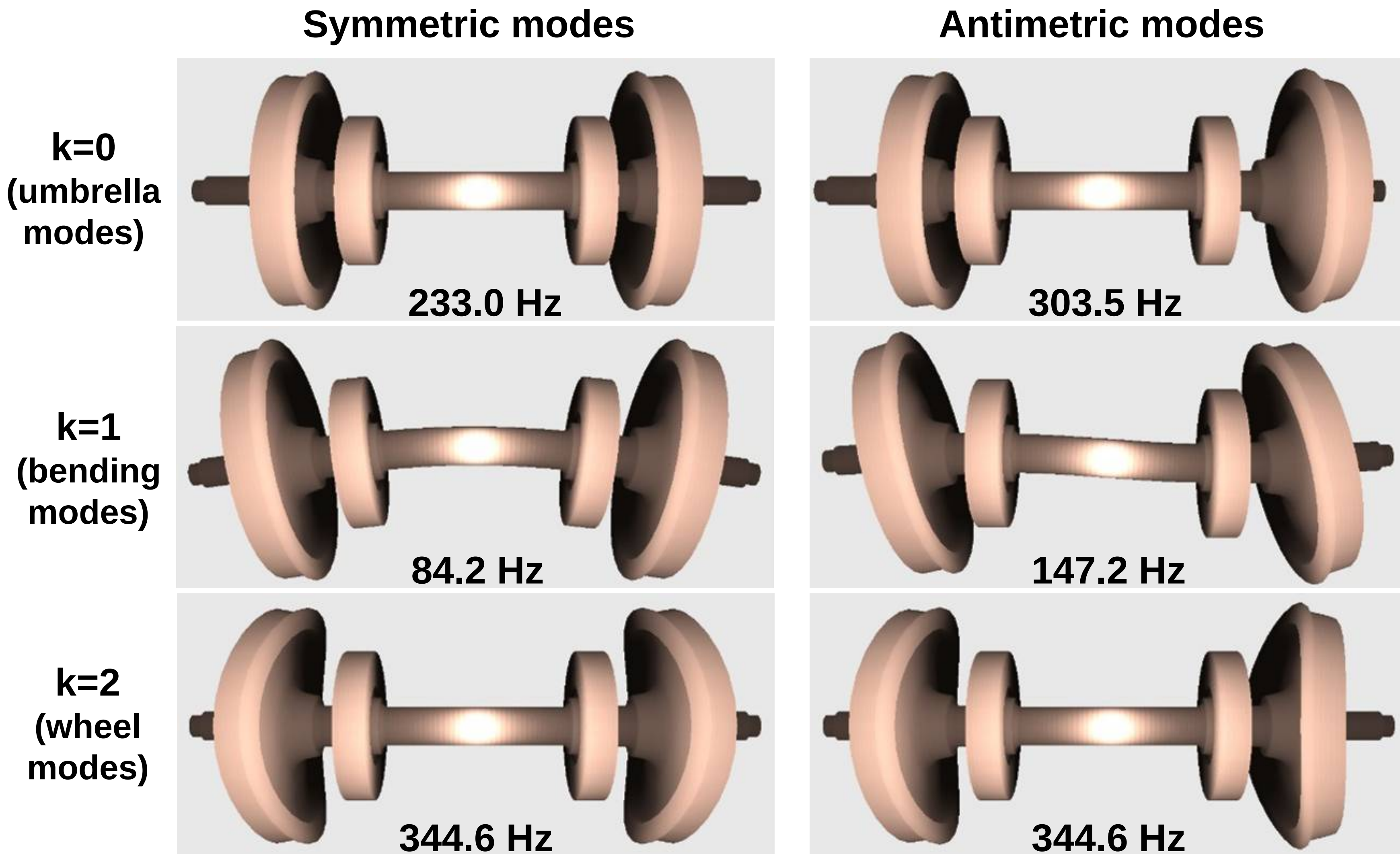
$$R(r,\theta,y,t) = R_k(r,y)\cos(k\theta+\beta)\cos(\omega_{0,k}t+\varphi)$$

$$T(r,\theta,y,t) = T_k(r,y)\sin(k\theta+\beta)\cos(\omega_{0,k}t+\varphi)$$

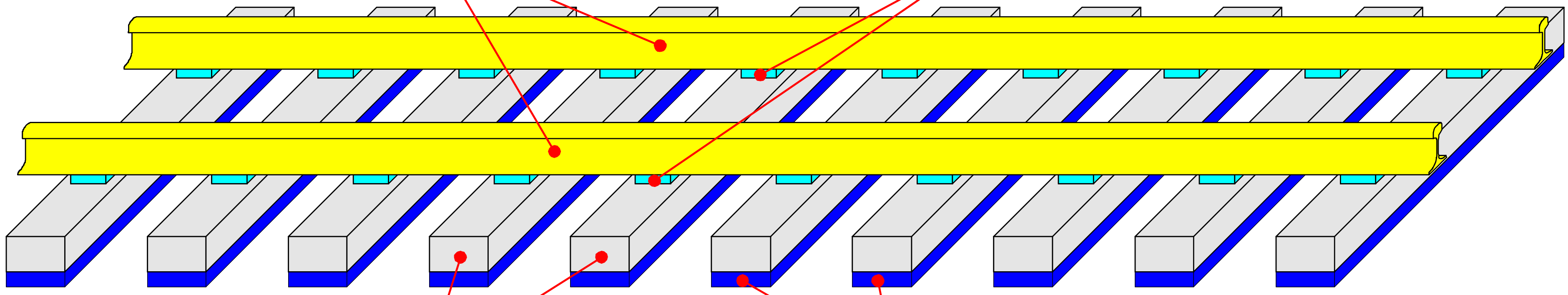
$$V(r,\theta,y,t) = V_k(r,y)\cos(k\theta+\beta)\cos(\omega_{0,k}t+\varphi)$$



Results of the FE calculation



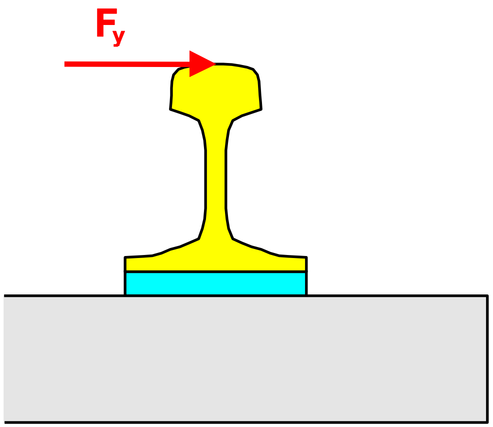
Structure of the track



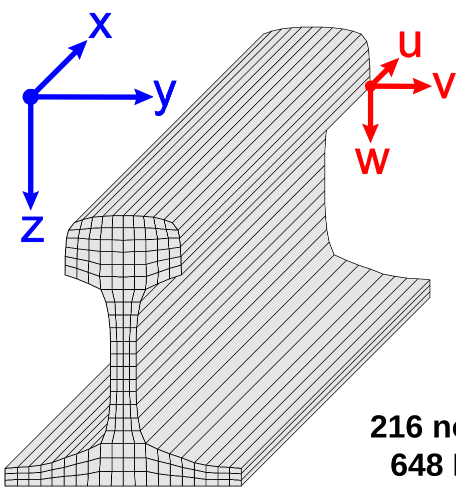
- Rails: Elastic bodies, identical boundary conditions at the ends
- Sleepers: Rigid bodies, 6 DoF, 64 sleepers in total
- Coupling of the bodies by linear spring/damper elements
- Linear system → *Modal decomposition possible*

Modelling of the rail

Eccentric loading of the rail by lateral forces → **Deformation of the rail's cross section possible**

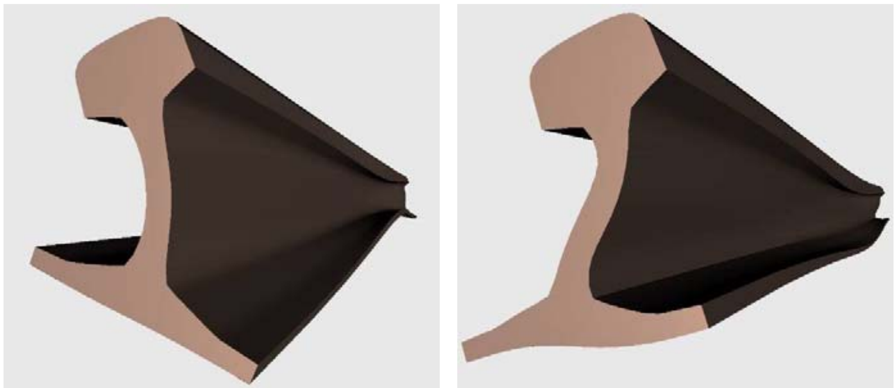


Finite-Element model of the rail



216 nodes, 648 DoF

Eigenmodes of the rail



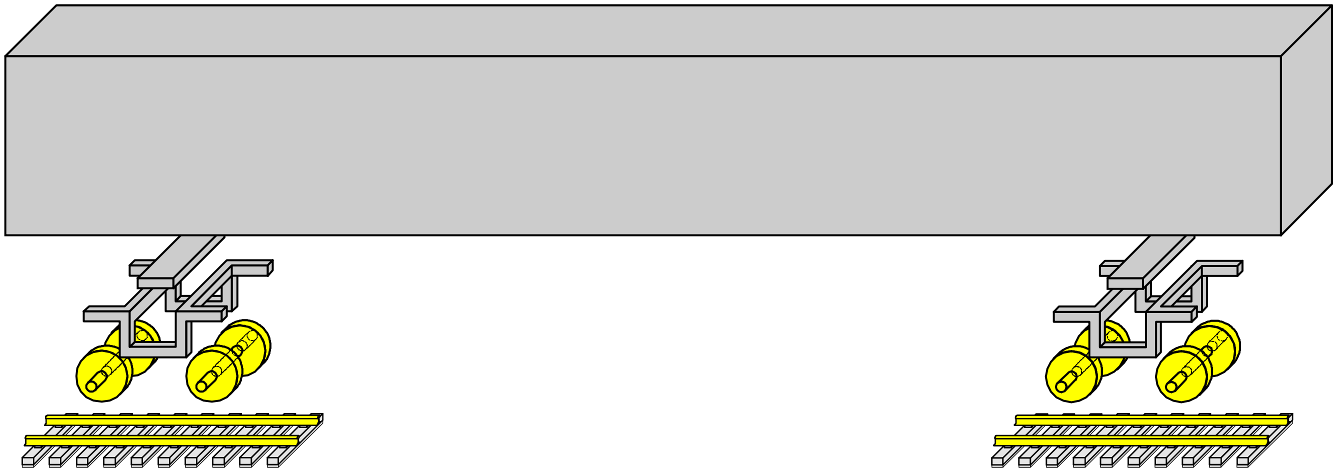
Semianalytic solution of Navier's equations for a prismatic structure

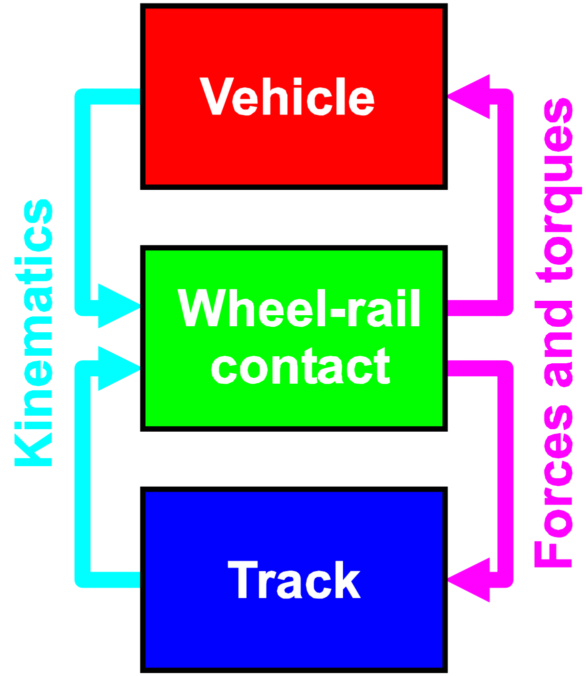
$$u(x,y,z,t) = U_k(y,z)\sin(\kappa_k x + \beta)\cos(\omega_{0,k} t + \varphi)$$

$$v(x,y,z,t) = V_k(y,z)\cos(\kappa_k x + \beta)\cos(\omega_{0,k} t + \varphi)$$

$$w(x,y,z,t) = W_k(y,z)\cos(\kappa_k x + \beta)\cos(\omega_{0,k} t + \varphi)$$

Vehicle-track system



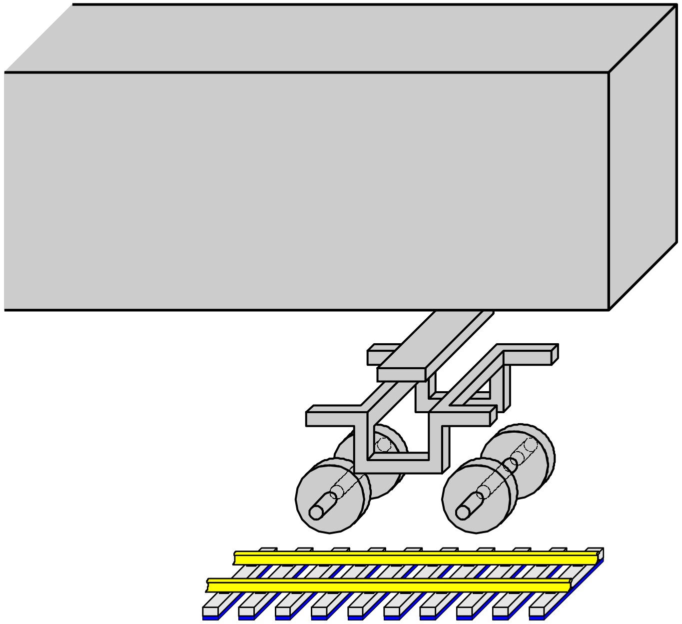


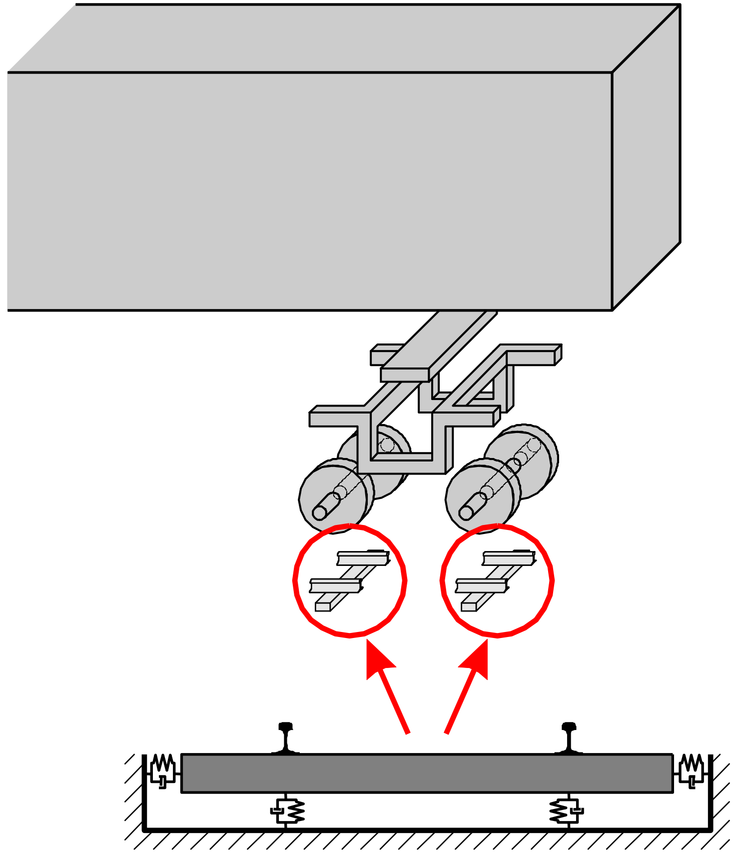
Vehicle: Elastic multi-body system (EMBS)

Wheel-rail contact: Nonlinear force element
- **Nonlinear contact geometry (wheel: S1002, rail: UIC 60, 1/40)**
- **Nonlinear contact forces (normal force: Hertz, tangential forces: Kalker/Polach)**

Track: Discrete-continuous system, two separate tracks, one for each bogie

Comparison of track models



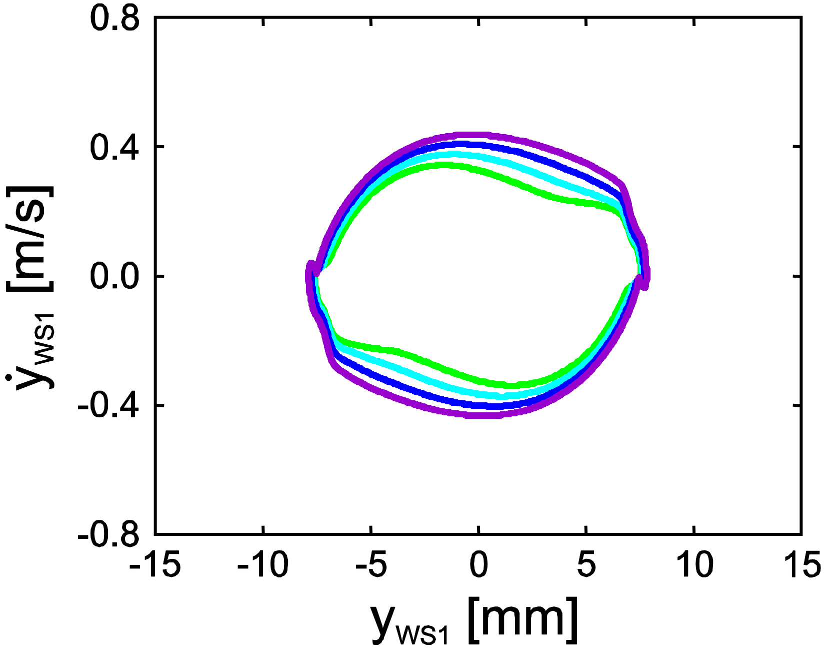


Detailed track model („elastic rails“)

Simple track model („rigid rails“)
- **1 rigid track element for each wheelset**
- **Viscoelastic support of the track element**

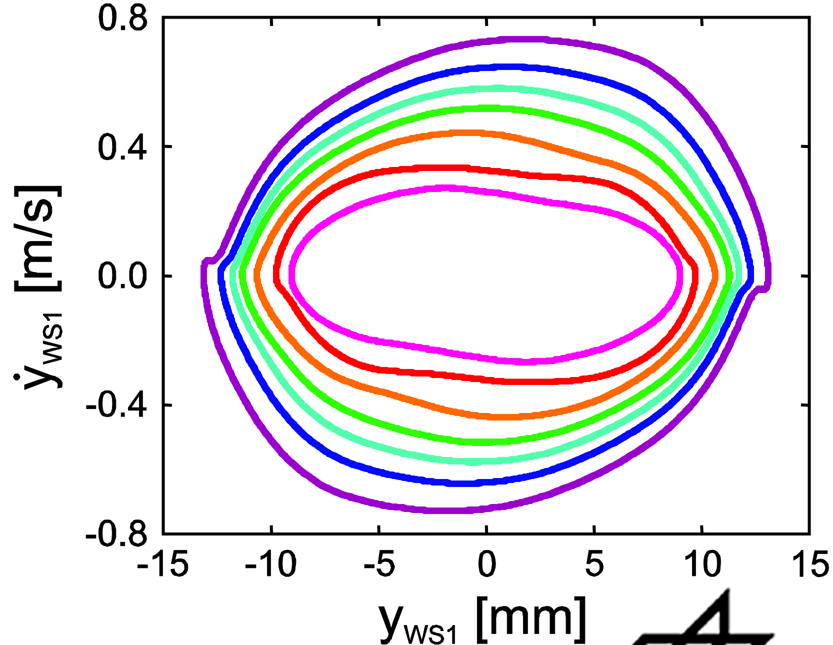
Influence of the structural elasticity

Rigid wheelsets / rigid rails



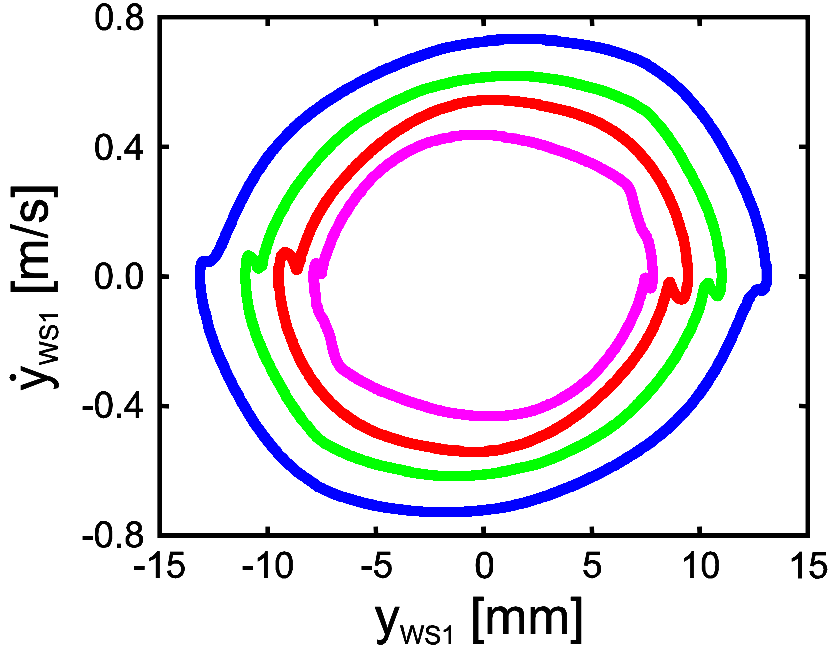
v_0 = 280 km/h
v_0 = 290 km/h
v_0 = 300 km/h
v_0 = 310 km/h
v_0 = 320 km/h
v_0 = 330 km/h
v_0 = 340 km/h

Elastic wheelsets / elastic rails

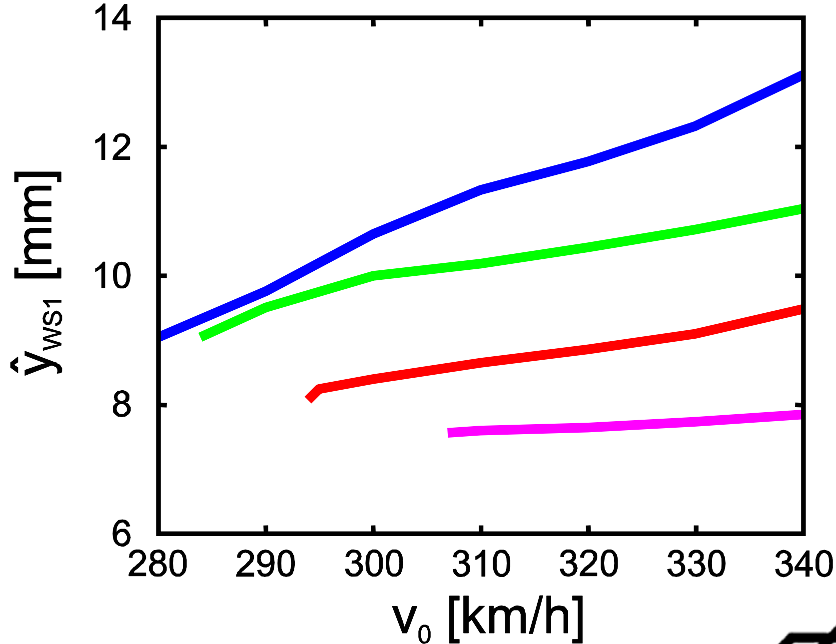


Influence of different structural elasticities

Rigid wheelsets / rigid rails
Elastic wheelsets / rigid rails
Rigid wheelsets / elastic rails
Elastic wheelsets / elastic rails



v_0 = 340 km/h



Concluding remarks

- Modelling of a passenger coach with elastic wheelsets
- Integration of the rotating elastic wheelsets
- Semianalytic FE model of the wheelsets (rotational symmetric body)
- Modelling of a track with discrete support by sleepers
- Semianalytic FE model of the rails (prismatic body)
- Structural elasticities lead to lower critical speed of the vehicle and to larger motion amplitudes of the wheelsets