Characteristic Parameters of Nonlinear Wheel/Rail Contact Geometry

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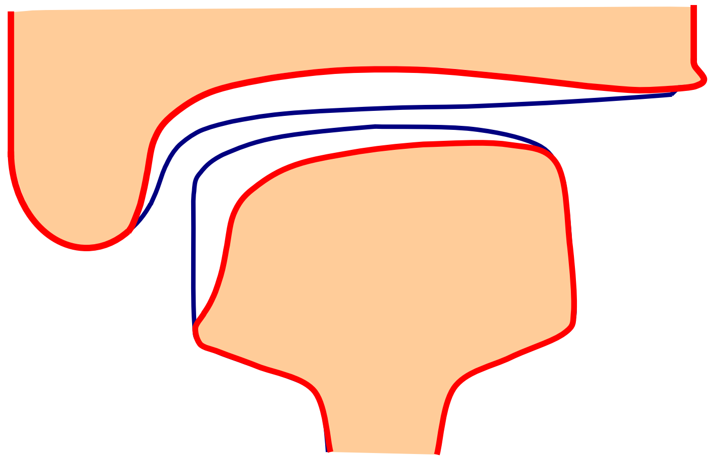
- **Effect of wheel/rail contact nonlinearity on vehicle dynamics**
- **Proposed parameters to characterise the wheel/rail contact**
- **Assessment of wheel/rail contact geometry examples**
- **Characteristic parameters and vehicle dynamic behaviour**
- **Conclusions**

Need for assessment of wheel/rail contact geometry

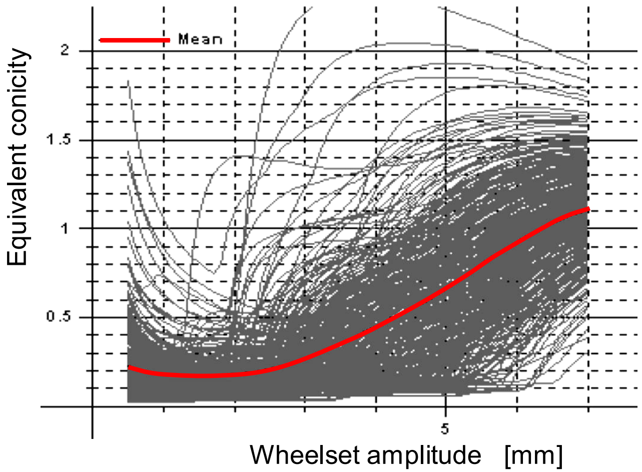


- Contact geometry wheel/rail or wheelset/track has an important influence on
  - running safety
  - running stability
  - oscillation behaviour
  - curving performance
- The actual geometry of wheels and rails changes due to the wear of wheels and rails, track gauge, rail inclination etc.
- Parameters like rail inclination and track gauge are not suited to assess the contact geometry
- The equivalent conicity is widely used by the railway community to characterise the contact geometry in
  - standards for vehicle acceptance (EN 14363, UIC 518) to assess the contact geometry during the on-track tests
  - Technical Specifications for Interoperability to assess
    - geometry of worn wheel profiles, combining the measured wheel profiles with theoretical rail profiles
    - geometry of rails of worn rails, combining the measured rail profiles with theoretical wheel profiles
- The equivalent conicity is considered mainly in relation to the stability assessment

Stability assessment and wheel/rail contact geometry

- Self excited oscillation of a railway wheelset (instability) considers a safety risk
- Railway practice confirmed the applicability of the equivalent conicity; however, it does not consider the nonlinearity
- Progress in nonlinear railway vehicle dynamics has contributed to understanding of effects of the wheelset/track nonlinearities on the behaviour of vehicles
- Progress of measuring technology allows sampling of a large amount of wheel and rail profile data

Large number of measured profiles



Another characterisation?

?

Single equivalent conicity value

0.XX

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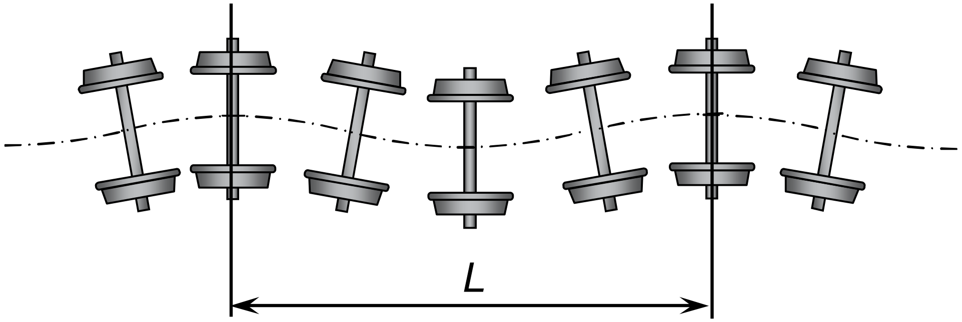
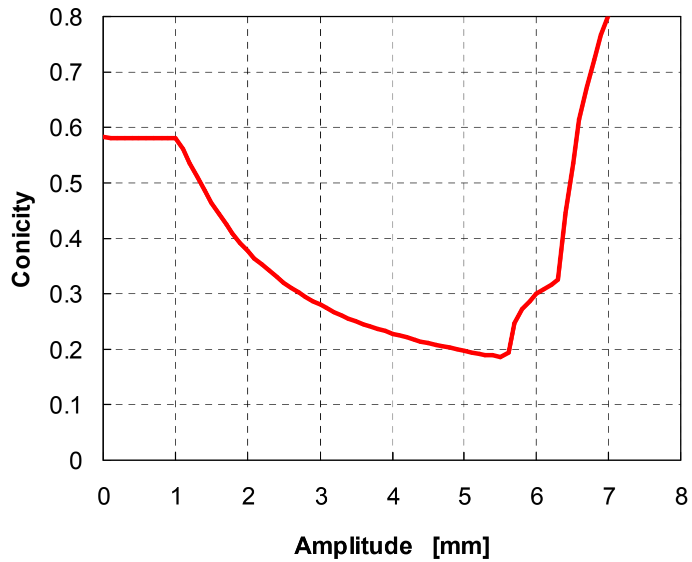
Equivalent conicity – a quasi-linear wheel/rail contact parameter

- Equivalent conicity can be calculated using the following quasi-linearisation methods:
  - harmonic linearisation
  - equivalent linearisation (UIC 519, prEN 15302)
  - linear regression of *Δr*-function (UIC 519, prEN 15302)
  - UK-method base on a stochastic wheelset displacement
- The nonlinearity of wheel/rail contact leads to a change of the slope of the rolling radii difference function
- Consequently, the equivalent conicity is dependent on the nonlinearity of wheel/rail contact geometry
- A characterisation of contact geometry wheelset/track by one conicity value does not consider contact nonlinearity
- A simplified characterisation of the contact geometry wheelset/track considering the effect of the contact nonlinearity is needed for the assessment of wheels and rails and for the specifications of wheel/rail contact geometry





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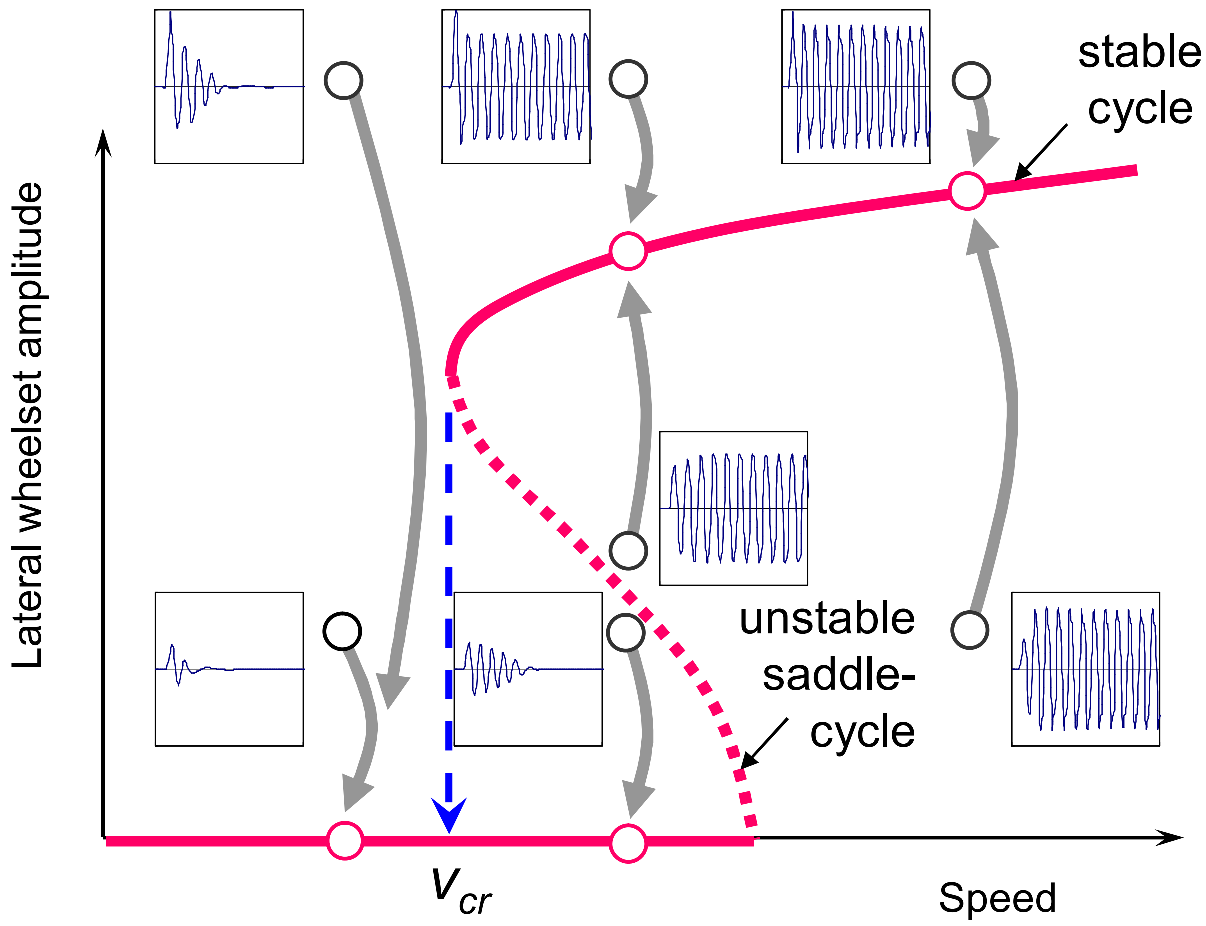
Stability assessment using bifurcation diagram

- Bifurcation diagram displays the amplitude of limit cycle in function of speed



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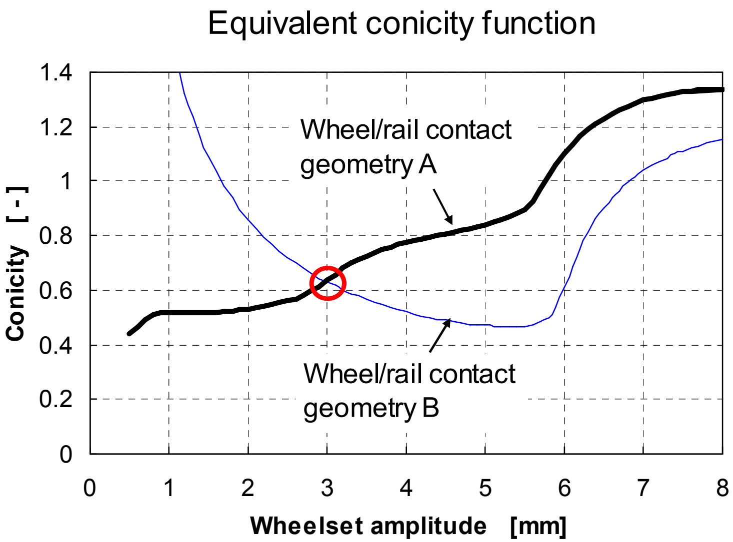
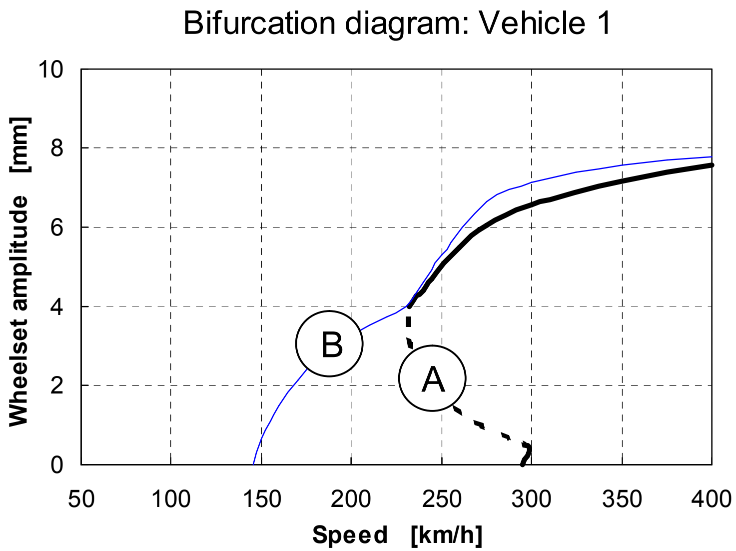
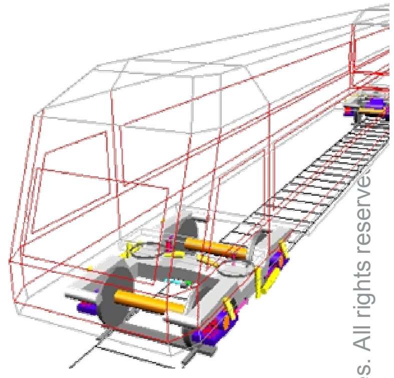
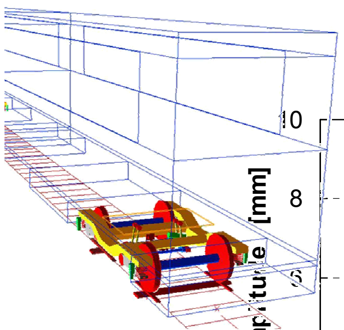
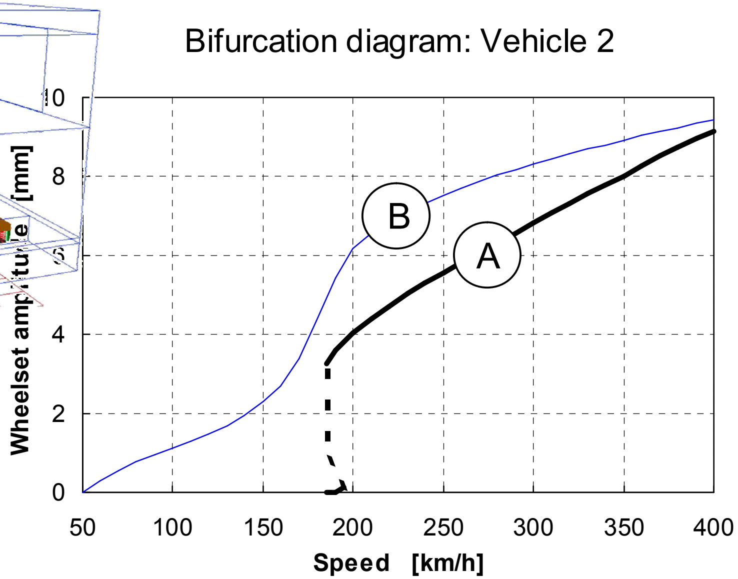
Contact geometry and stability assessment using bifurcation diagram

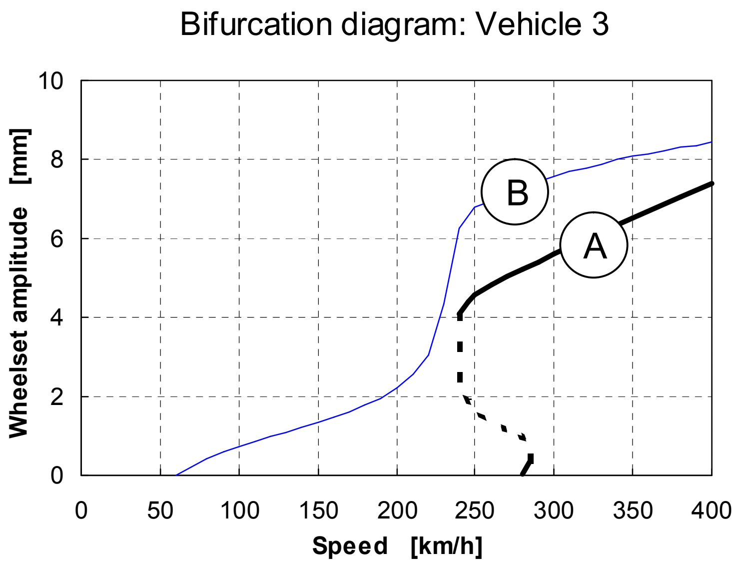


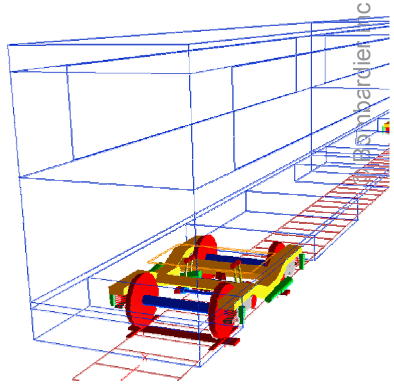












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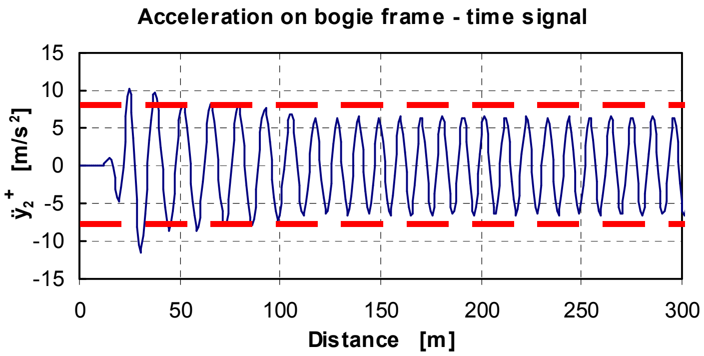
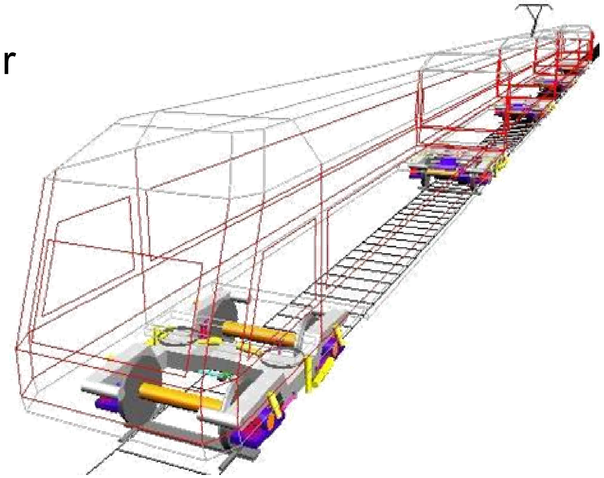
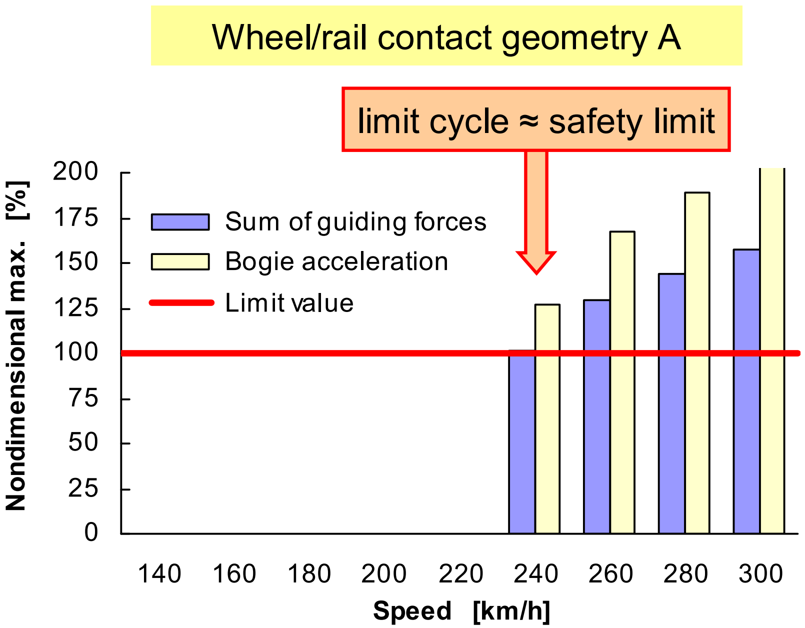
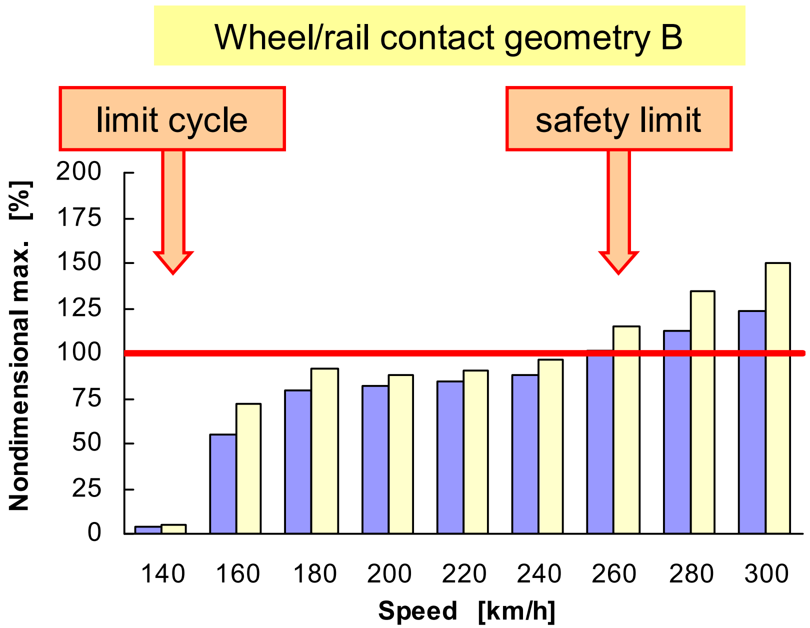
Effect of wheel/rail nonlinearity on the vehicle's behaviour at the stability limit

- Two contact geometries with equal conicity at the amplitude of 3 mm
- Assessment of the instability safety criteria according to EN 14363 after an excitation by a single lateral disturbance





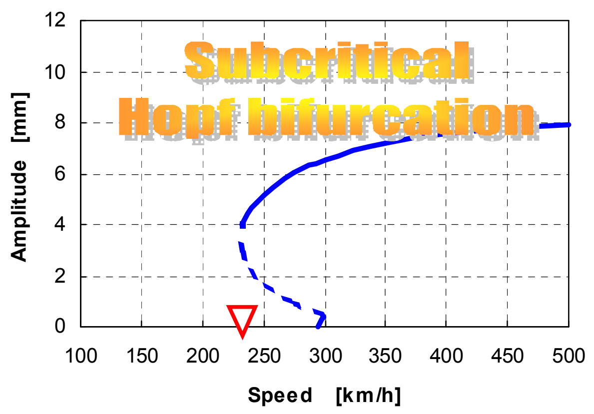


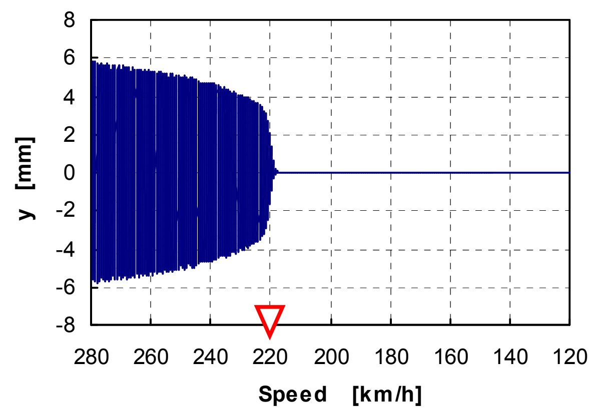


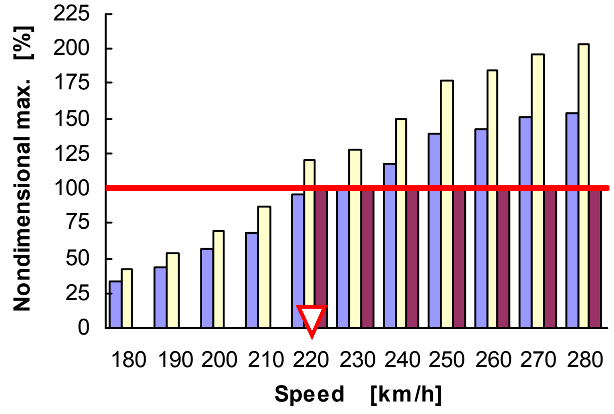
Effect of wheel/rail nonlinearity on different stability assessment methods

Bifurcation diagram | Simulation with decreasing speed on ideal track | Stability assessment according to standards on measured track

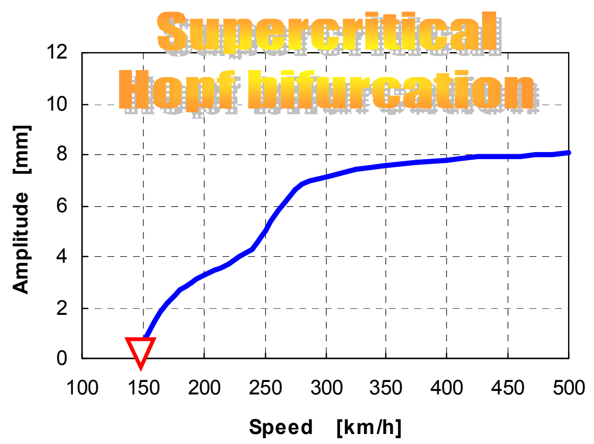
Contact geometry A

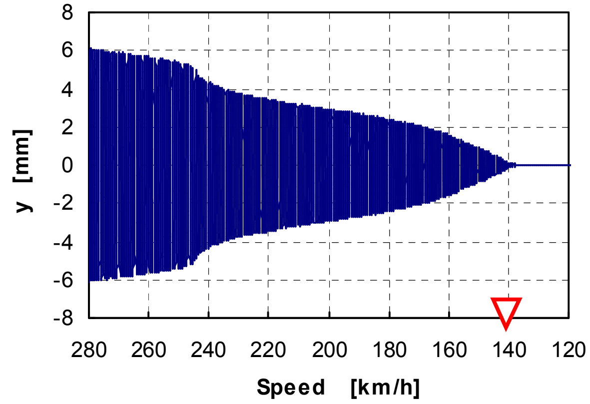


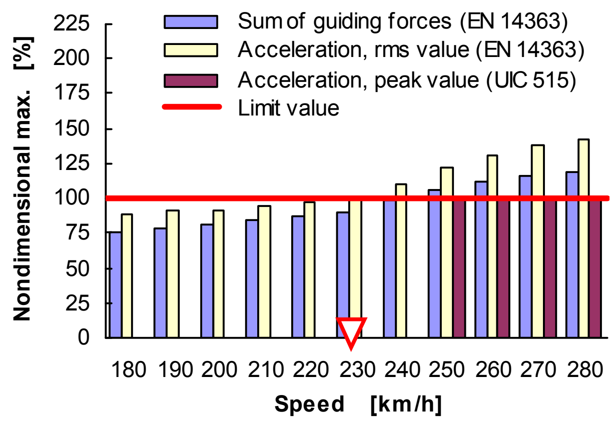




Contact geometry B







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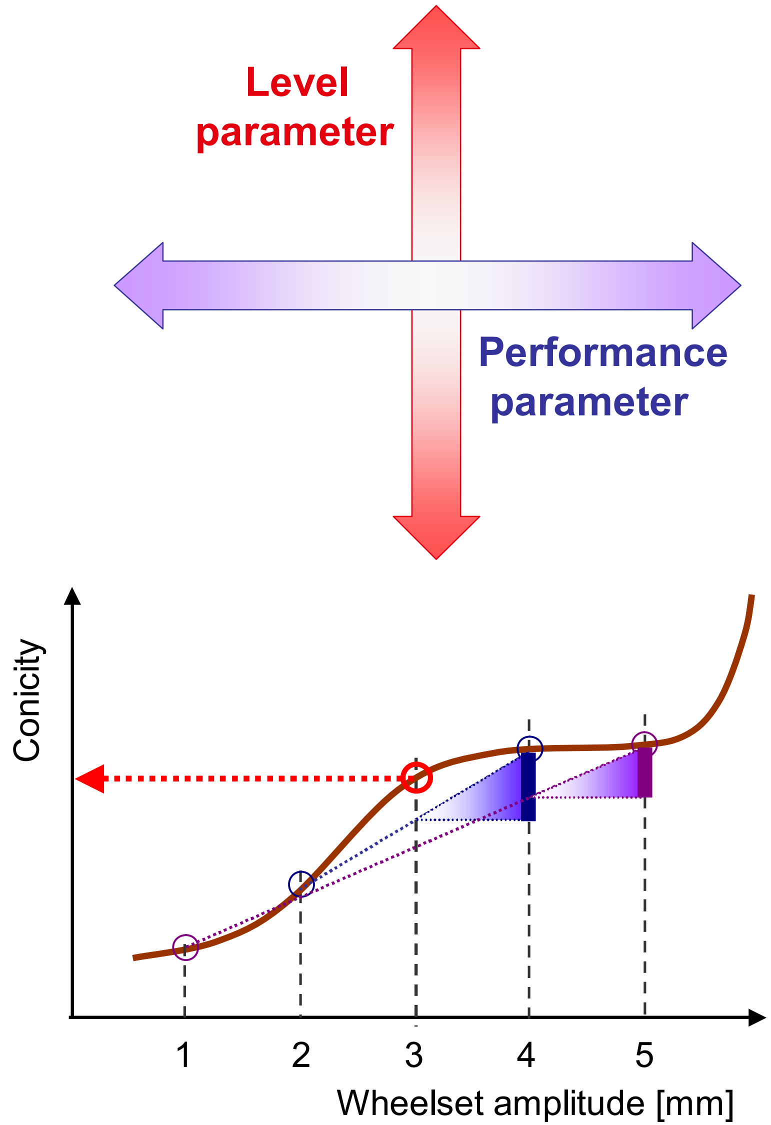
Proposed definition of wheel/rail characteristic parameters

- Parameter 1 – Level parameter:
  - Definition: Equivalent conicity for a wheelset amplitude of 3 mm
  - Usage: Assessment of contact geometry regarding the instability safety limit according to EN 14363
- Parameter 2 – Nonlinearity parameter:
  - Definition: Slope of the equivalent conicity function
  - Usage:
    - Vehicle performance at the stability limit
    - Sensitivity of vehicle to the lateral excitation by track irregularity
  - Definition 1:

$$\lambda_{N,1} = \frac{\lambda_4 - \lambda_2}{2}$$

  - Definition 2:

$$\lambda_{N,2} = \frac{\lambda_5 - \lambda_1}{4}$$



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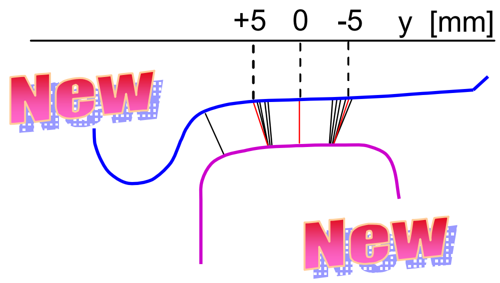
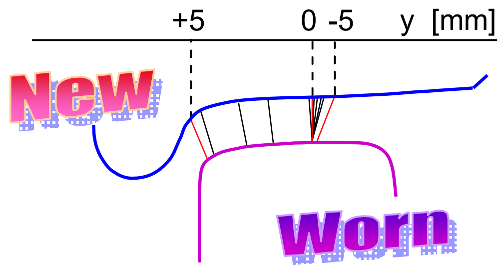
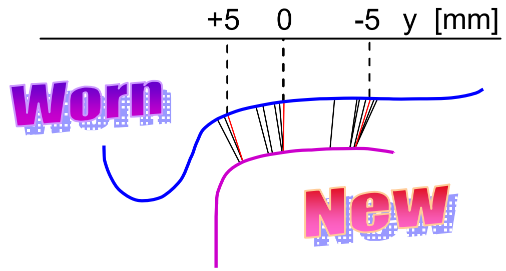
Examples of contact geometry wheelset/track

- Examples of contact geometry wheelset/track
  - Six examples wheel/rail profile combinations
  - Theoretical as well as worn profiles
  - Three levels of equivalent conicity
  - Two different contact nonlinearities for each conicity level





- Methods used to calculate the equivalent conicity
  - Harmonic linearisation, elastic wheel/rail contact with a wheel load of 70 kN
  - Harmonic linearisation, rigid wheel/rail contact
  - Equivalent linearisation by application of Klingel formula according to UIC 519
  - Linear regression of the Δr-function according to UIC 519
  - UK-method for a stochastic wheelset displacement with a standard deviation of 1.25, 2.50 and 3.75 mm



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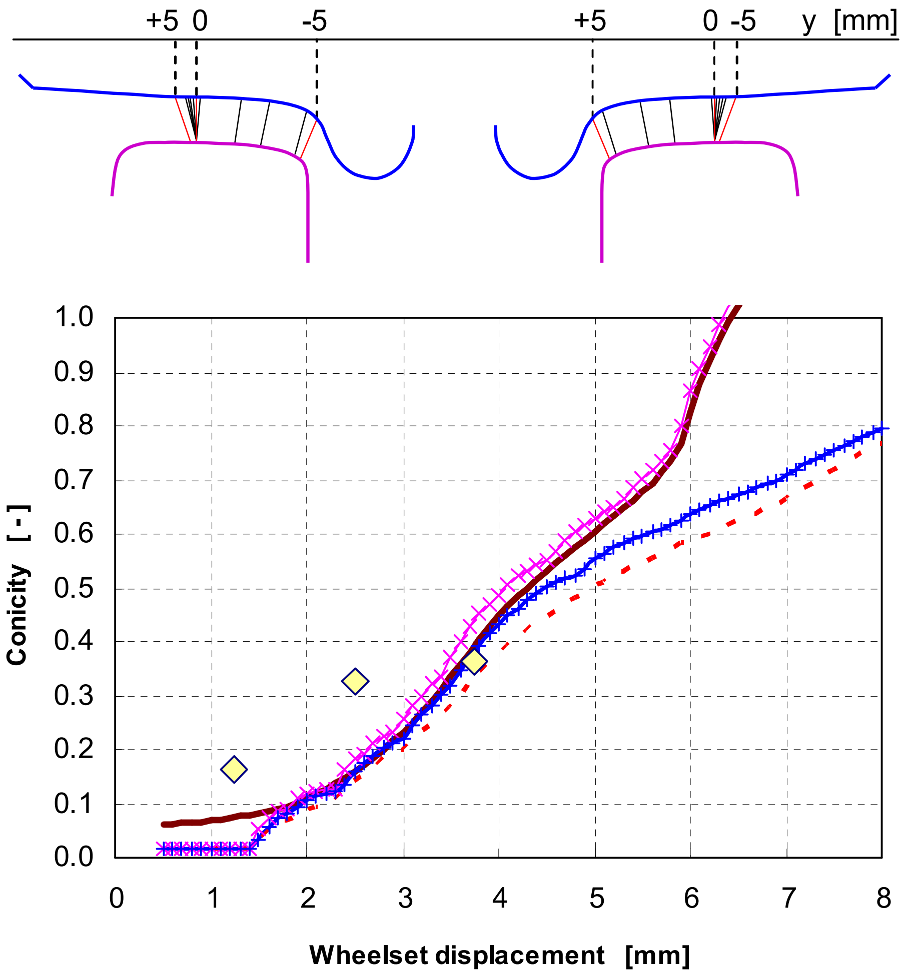
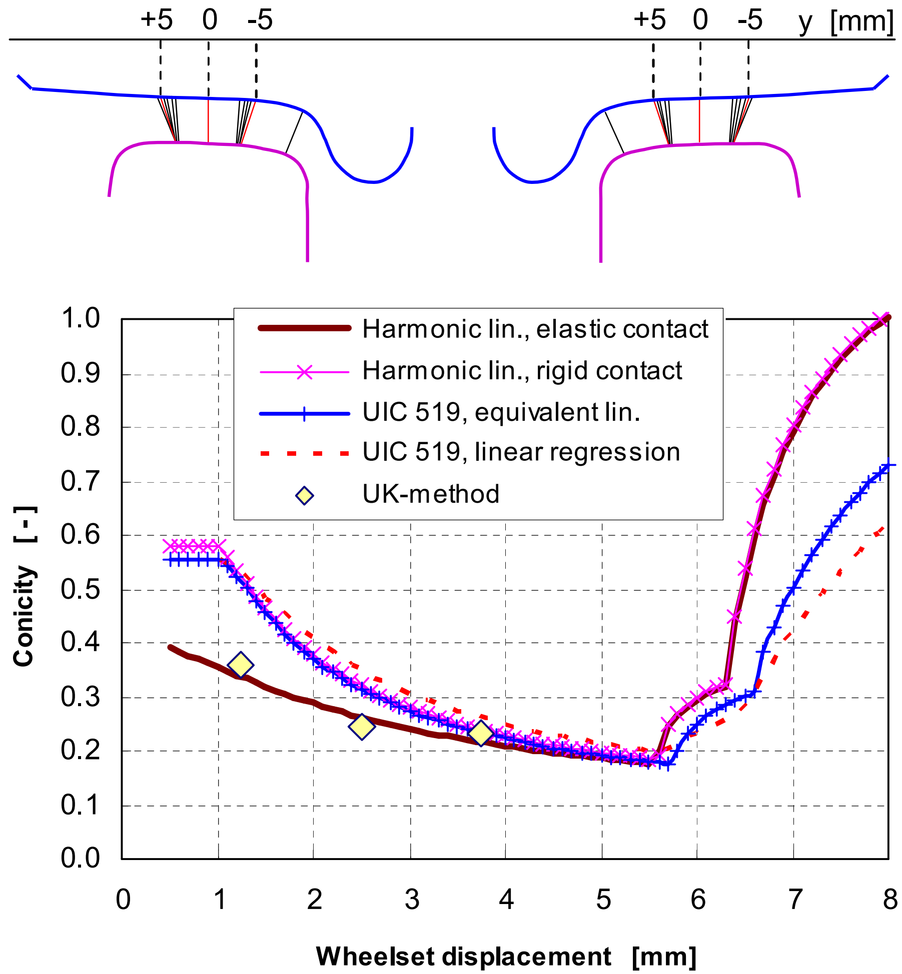
Middle equivalent conicity

- Wheelset/track 1a



- Wheelset/track 1b



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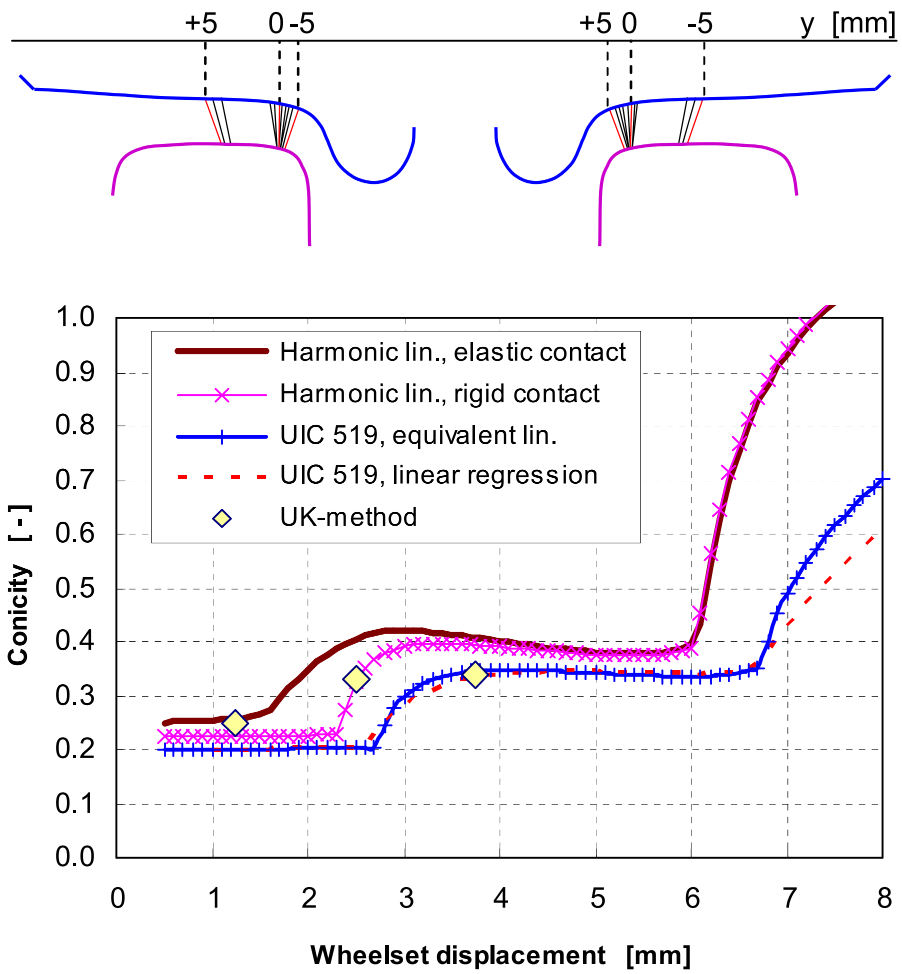
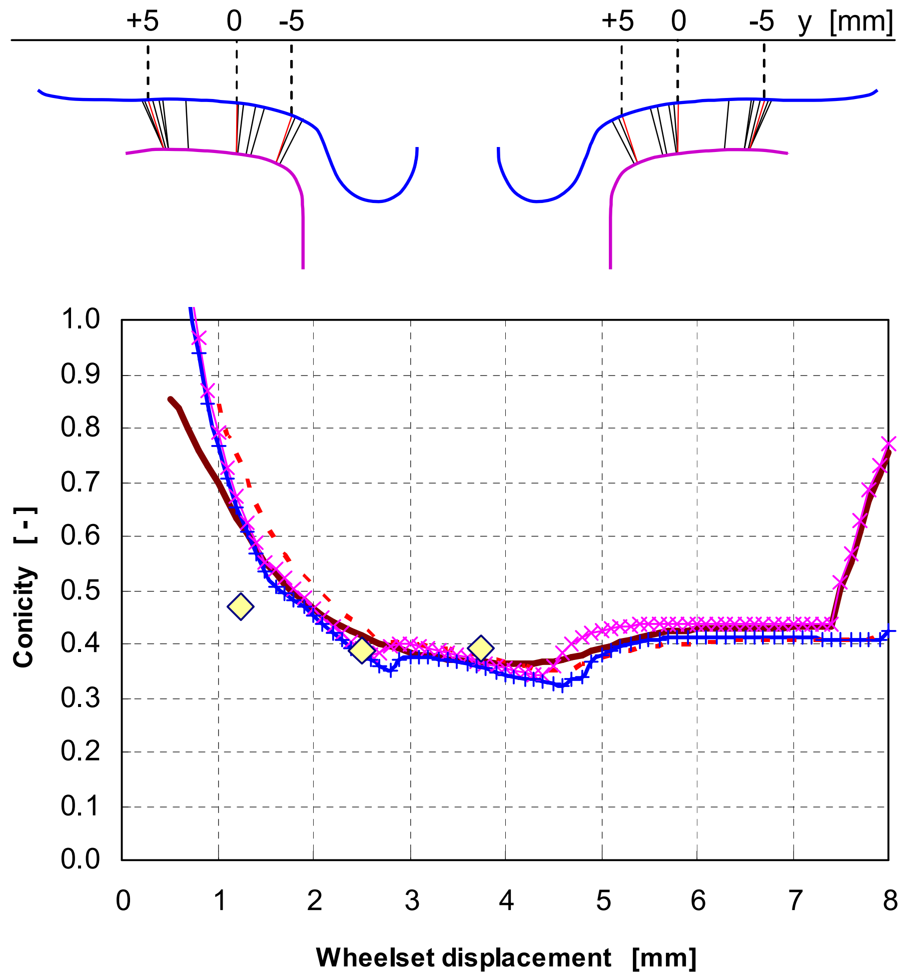
High equivalent conicity

- Wheelset/track 2a



- Wheelset/track 2b



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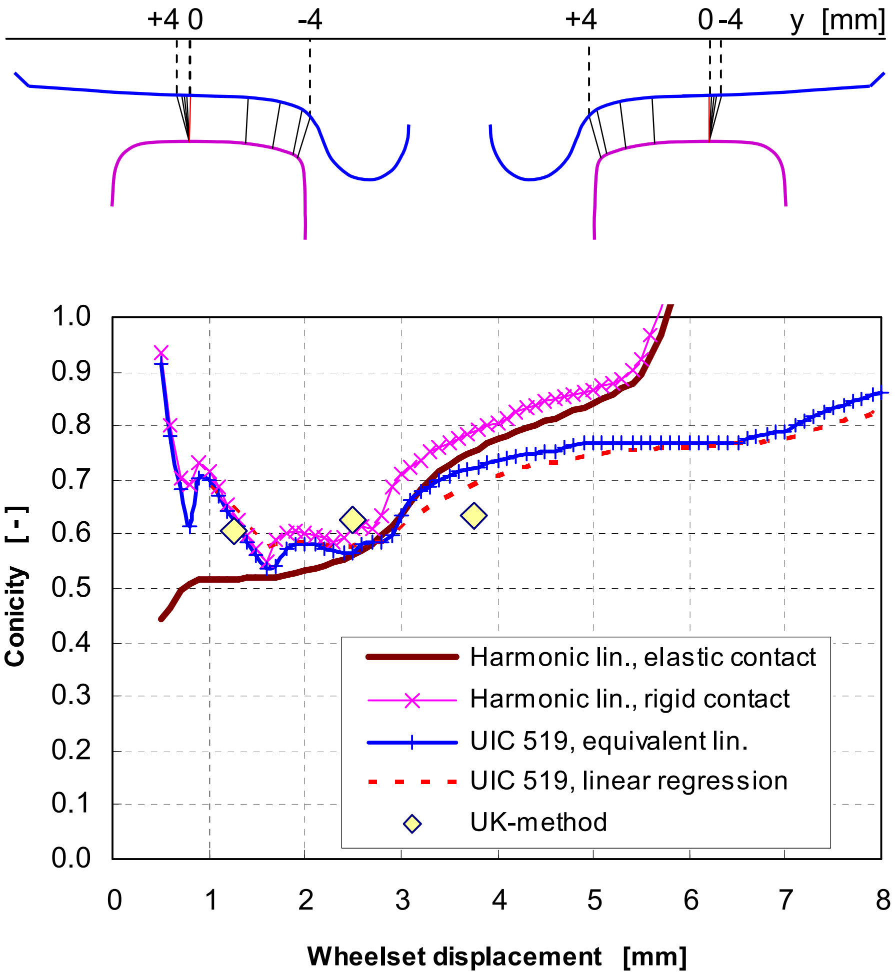
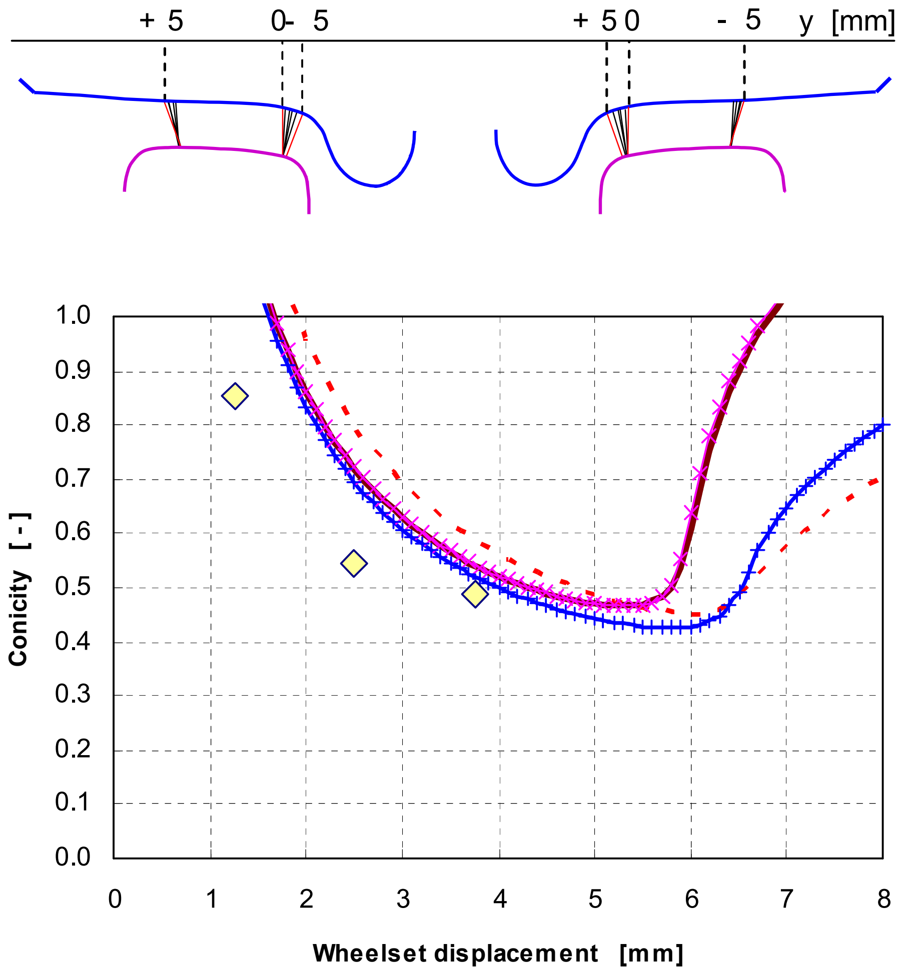
Very high equivalent conicity

- Wheelset/track 3a



- Wheelset/track 3b



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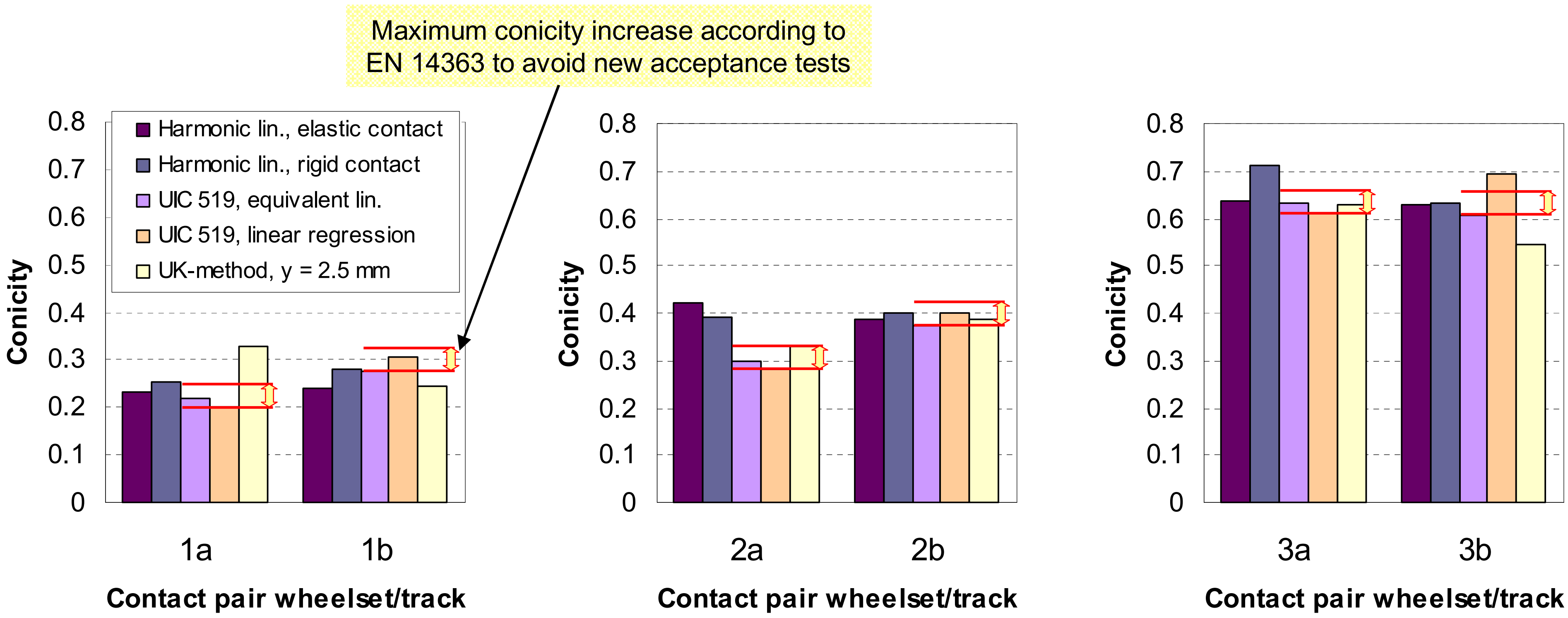
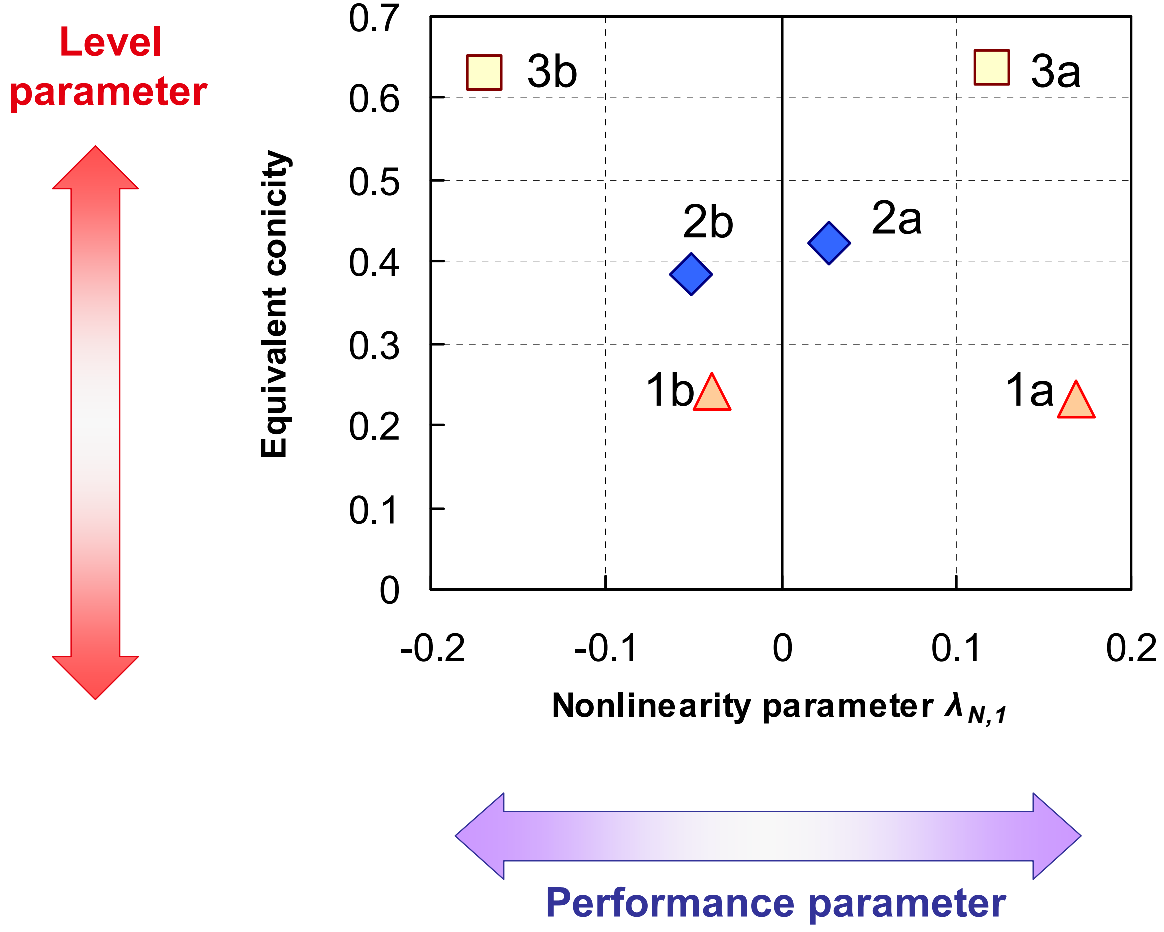
Comparison of conicity values for an amplitude of 3 mm



- Conclusion from this comparison:
  - Conicity is only an approximate parameter
  - It is not reasonable to insist on very exact conicity values in the specifications

Characterisation of investigated wheel/rail profile pairs by two parameters



- Nonlinearity parameter
- Definition 1:

$$\lambda_{N,1} = \frac{\lambda_4 - \lambda_2}{2}$$

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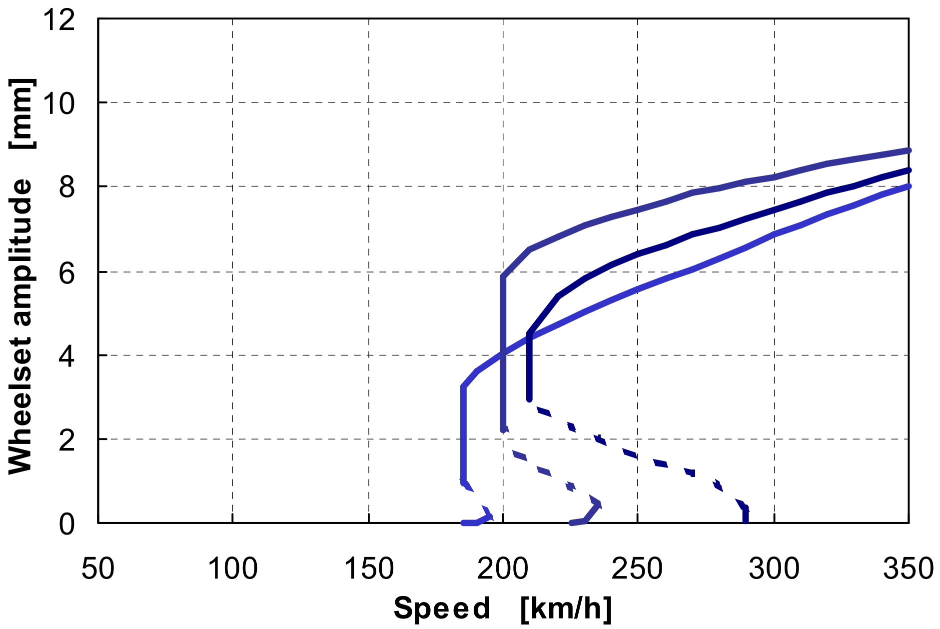
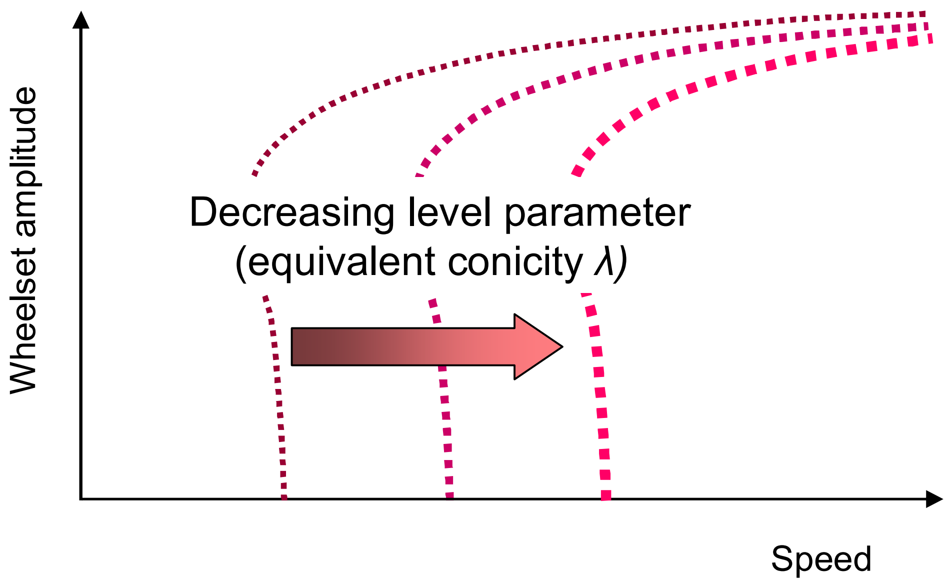
Bifurcation diagram and variation of the level parameter

- Nonlinearity parameter 0.03 ÷ 0.17
- Conicity: 0.64 → 0.42 → 0.23





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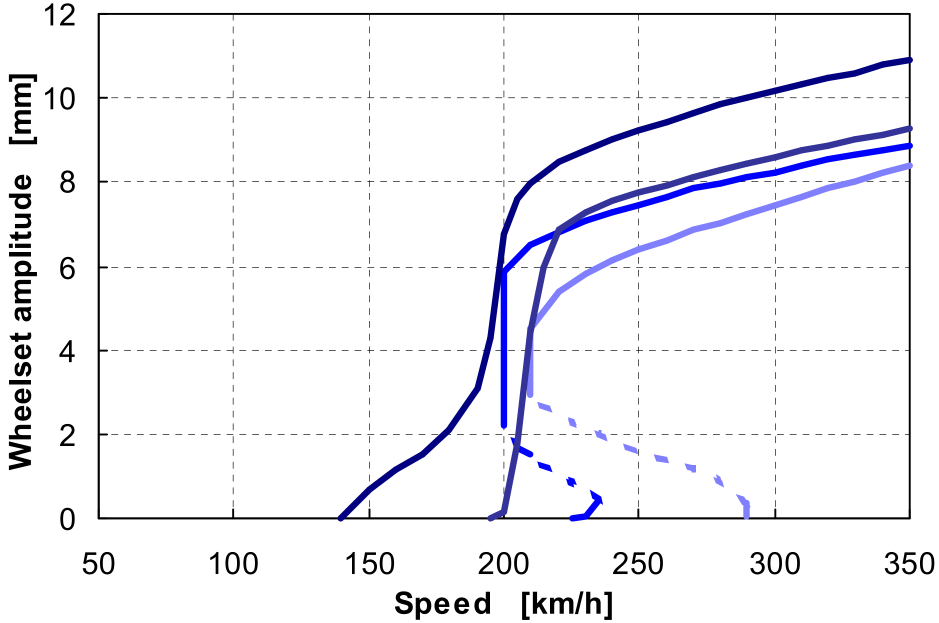
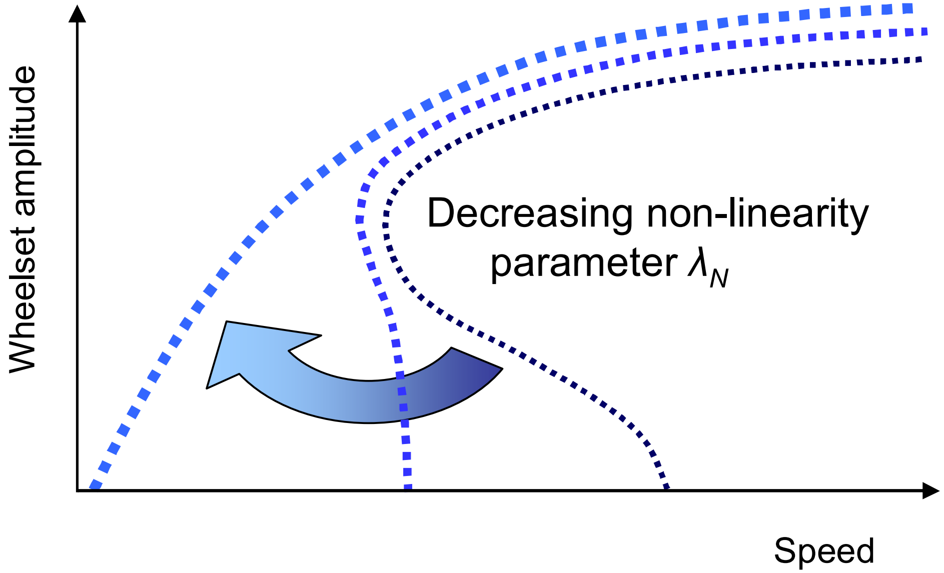
Bifurcation diagram and variation of the nonlinearity parameter

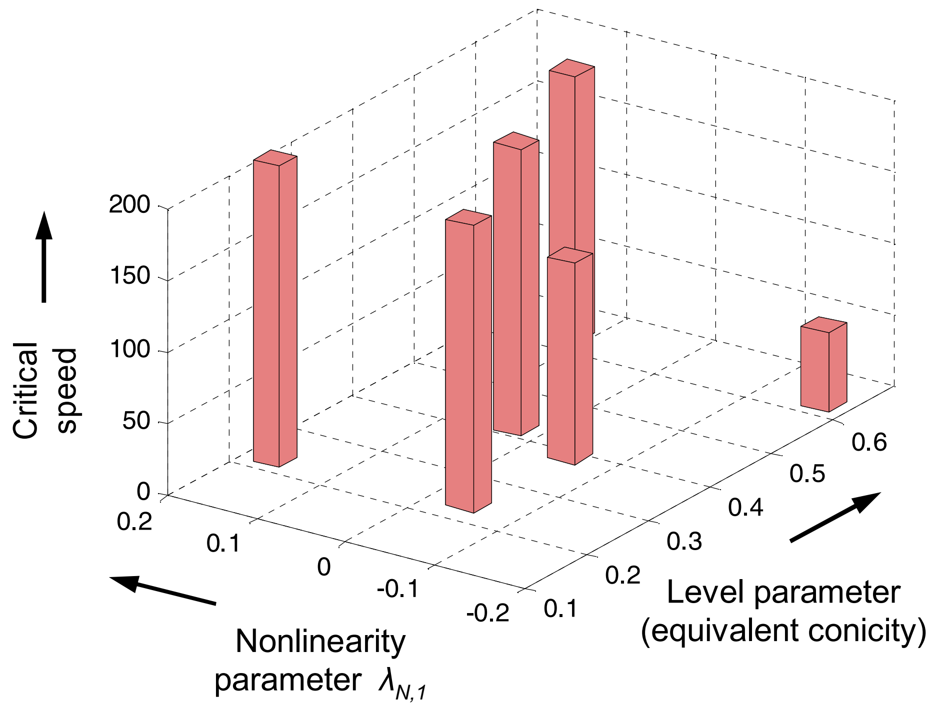
- Conicity: 0.23 ÷ 0.42
- Nonlinearity parameter: 0.17 → 0.03 → -0.04 → -0.05



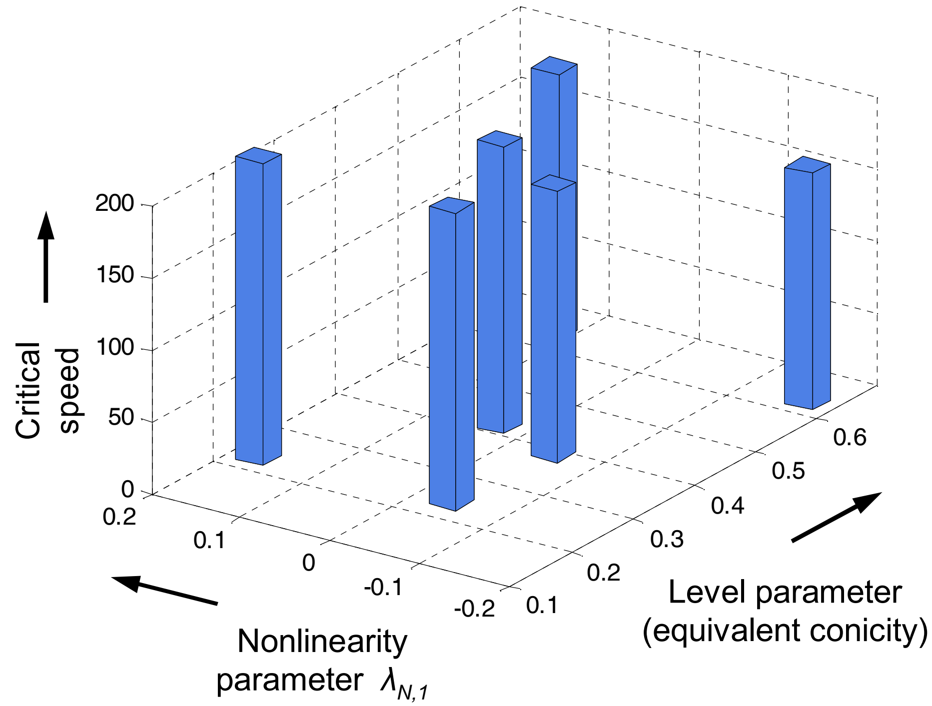


Effect of nonlinearity parameter on the critical speed

- Nonlinear critical speed



- Speed at which a limit cycle with a wheelset amplitude of 3 mm appears



- The proposed nonlinearity parameter can
  - explain differences between stability assessments by different methods using the contact geometry with the same conicity
  - explain differences between theoretical studies and on-track tests
  - contribute to better understanding of vehicle behaviour

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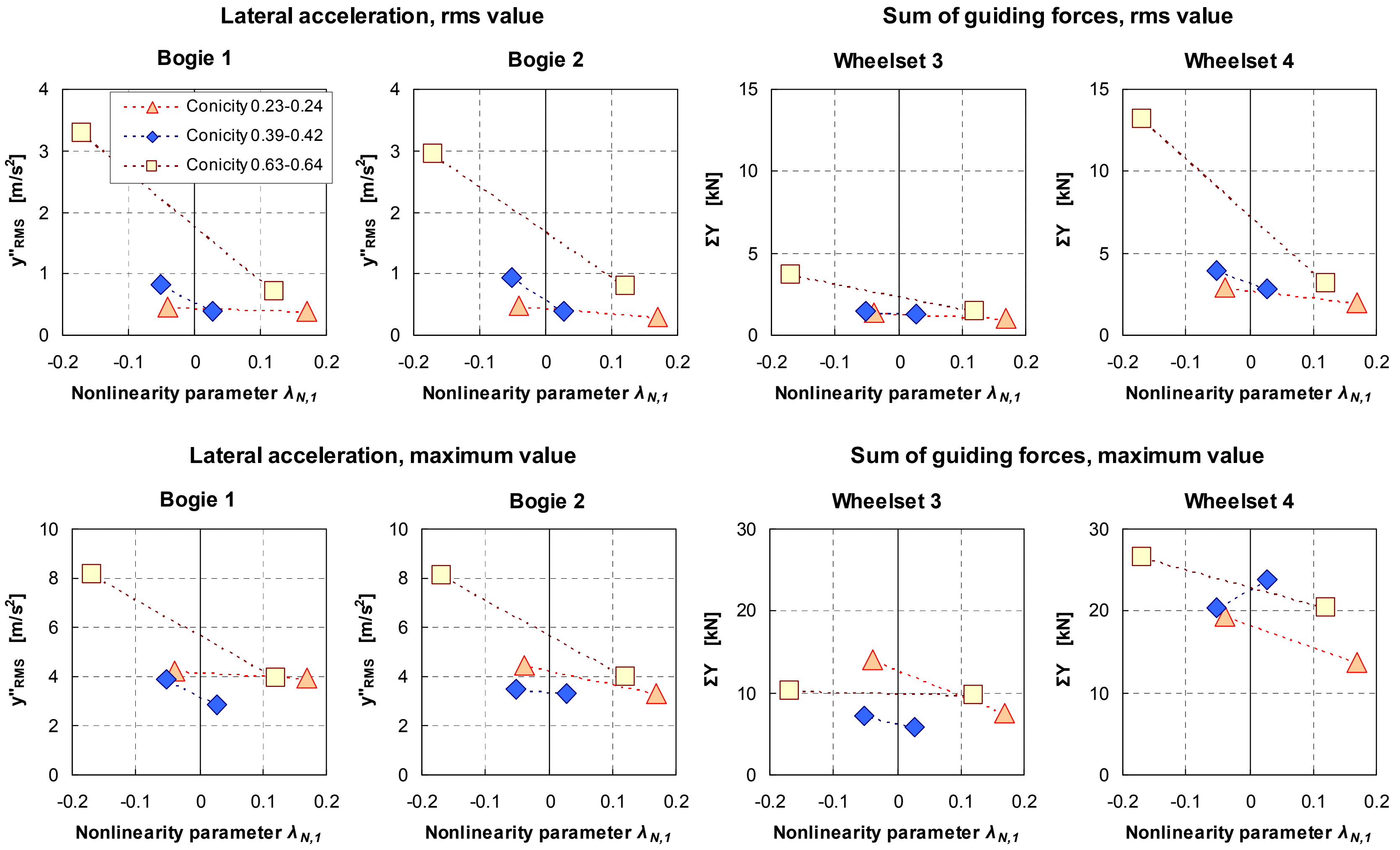
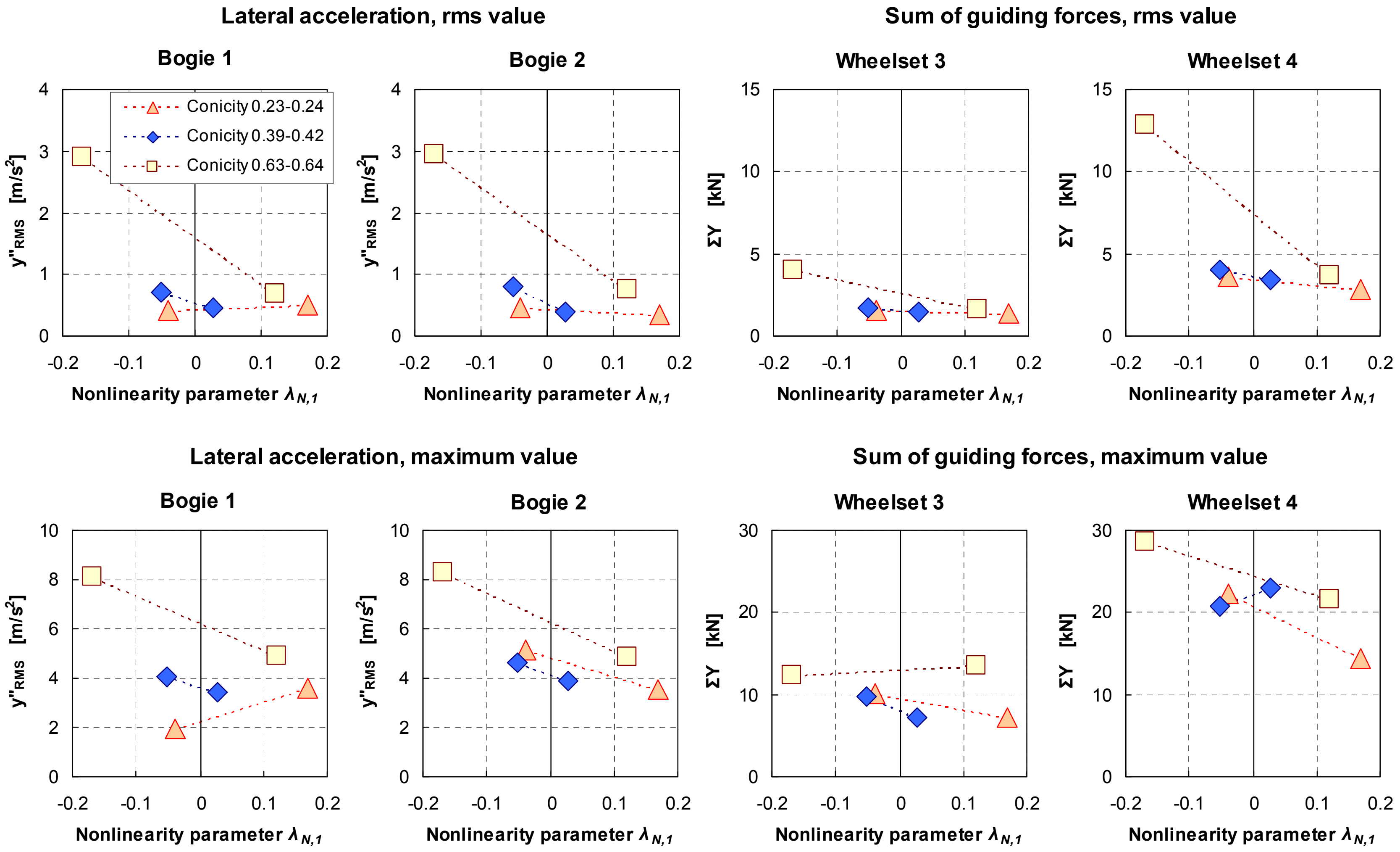
Effect of nonlinearity parameter on the vehicle's behaviour on a straight track with measured irregularities

- Measured track irregularity data, track 1



Effect of nonlinearity parameter on the vehicle's behaviour on a straight track with measured irregularities

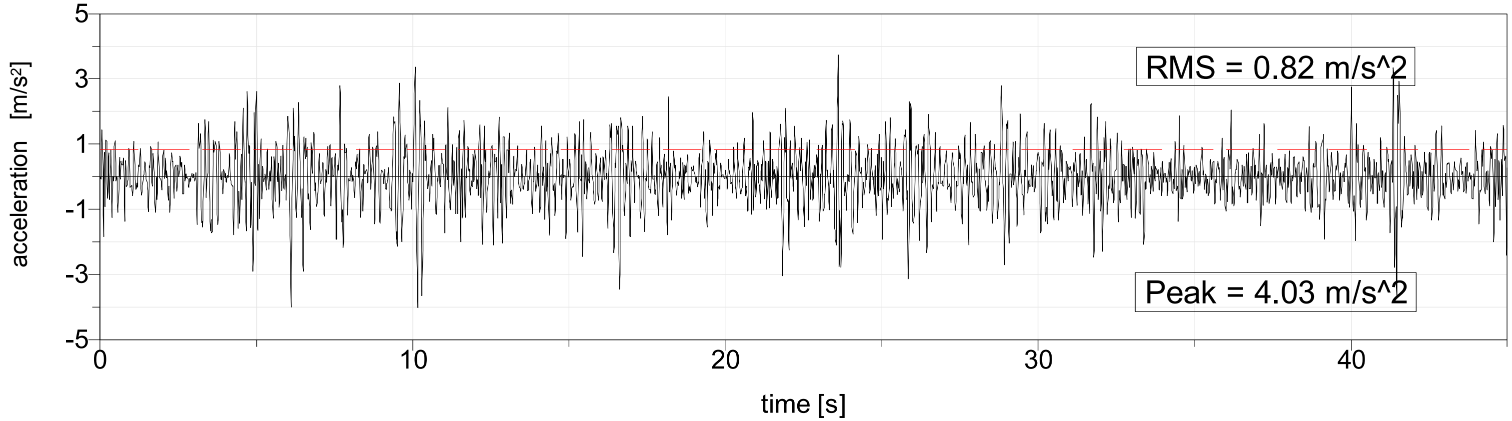
- Measured track irregularity data, track 2



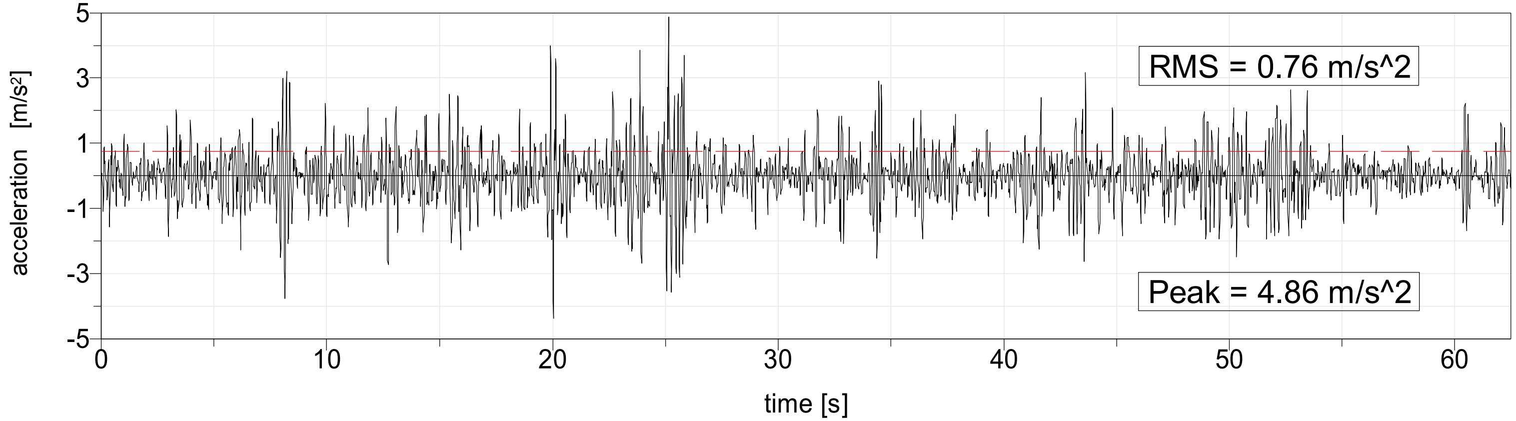
Influence of track irregularities: Comparison of time plots

- Example: Lateral acceleration on the bogie frame, bogie 2

- Track 1



- Track 2



- The wheel/rail contact geometry has a dominating influence
- The resultant rms values are similar for the same wheel/rail contact geometry
- The results are related to the proposed nonlinearity parameter

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Conclusions

- A new description characterising the wheel/rail contact geometry by two parameters is proposed
- The equivalent conicity for a wheelset amplitude of 3 mm is applied as the first parameter related to the risk of safety relevant self excited oscillations
- The second, newly introduced parameter allows an assessment of the expected behaviour at the stability limit and the sensitivity to the lateral track irregularities
- An assessment of the proposed parameters on six wheelset/track examples confirmed a correlation between these parameters and railways vehicle dynamic behaviour
- The proposed definition of characteristic parameters allows an improved but still comprehensive description of nonlinear wheel/rail contact geometry
- Further investigations, analyses and on-track tests are required to confirm the observed correlation and to assess the applicability of the proposed wheel/rail characterisation

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