Comparability of the Non-linear and Linearized Stability Assessment During Railway Vehicle Design

Oldrich POLACH

Bombardier Transportation

Winterthur, Switzerland

BOMBARDIER

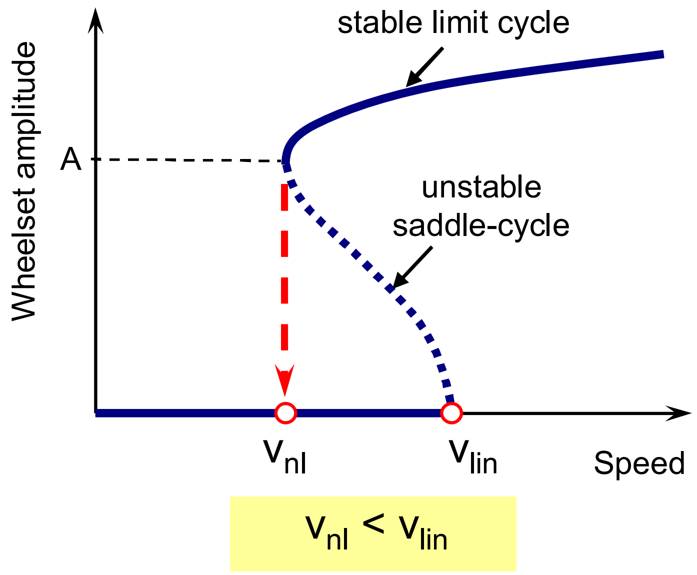
Contents

BOMBARDIER

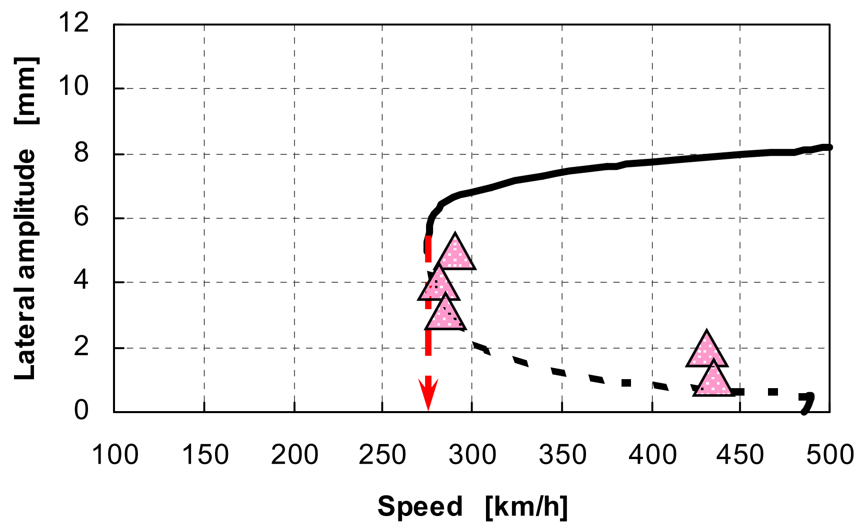
Introduction

- The dynamics of the vehicle at the stability limit is nonlinear by
  - contact geometry wheelset/track
  - creep forces between wheel and rail

- Usual presentation in literature:



- Real applications in simulation tools: Quasi-linear wheel/rail contact model



- The relation between the linear and non-linear critical speed depends on the method and parameters applied

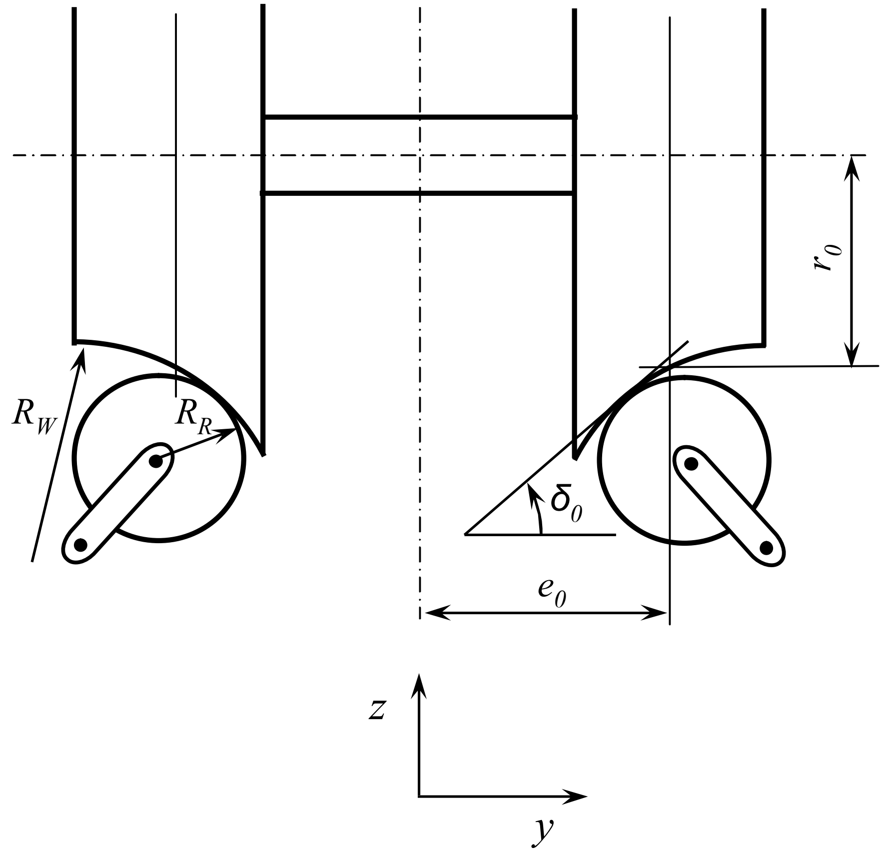
BOMBARDIER

Quasi-linear contact model wheelset/track

- Contact geometry function:
  - Difference of rolling radii

$$\Delta r = r_l - r_r = f(y)$$

  - Contact angle difference
  - Wheelset roll angle



- Linearized parameters:
  - Equivalent conicity as a function of wheelset amplitude *A*

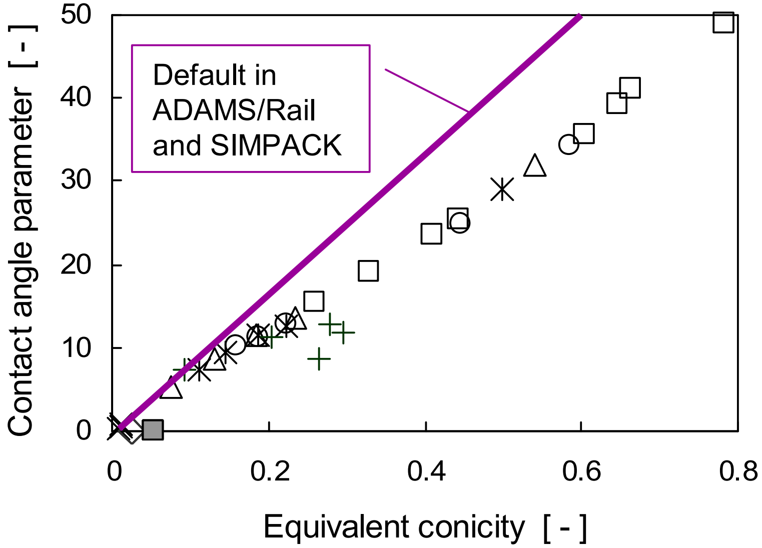
$$\lambda(A) = \frac{1}{2\pi A} \int_0^{2\pi} \Delta r(A \sin\varphi) \cdot \sin\varphi \, d\varphi$$

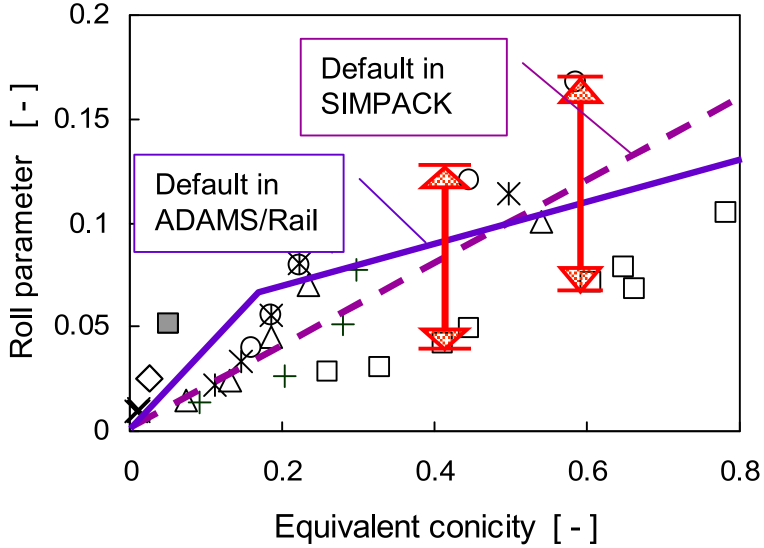
  - Contact angle parameter
  - Roll parameter

- Is the equivalent conicity sufficient to specify the quasi-linear contact model?

BOMBARDIER

Linearization parameters for real profile combinations



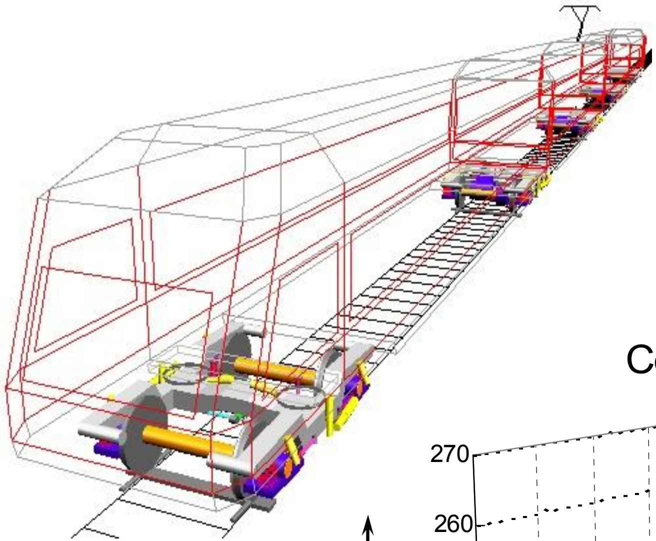


Wheel/rail combinations :

- △ S1002 / UIC60 1:40
- ✳ S1002 / UIC54 1:40
- ◇ Cone 1:40 / UIC60 1:20
- + P8 / UIC60 1:20
- × S1002 / UIC60 1:20
- ○ S1002 / UIC54E 1:40
- ■ Cone 1:20 / 115RE 1:40
- □ S1002 / UIC54E 1:40 worn crown

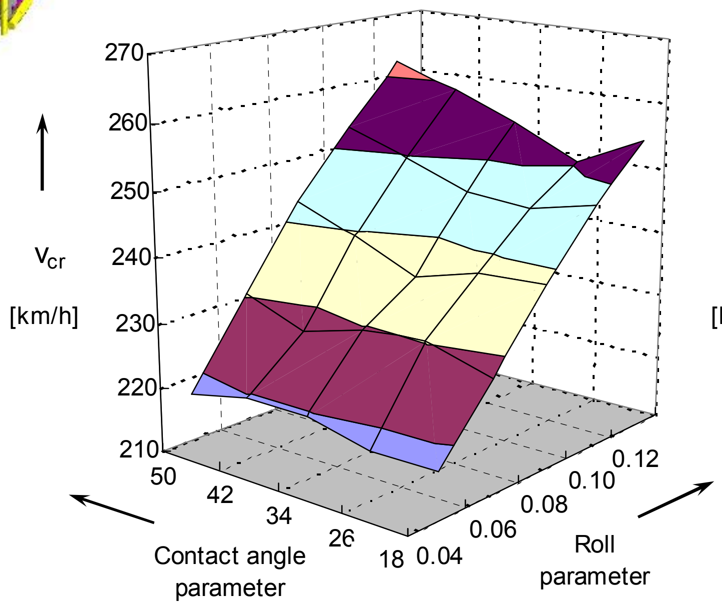
BOMBARDIER

Influence of contact angle and roll parameters

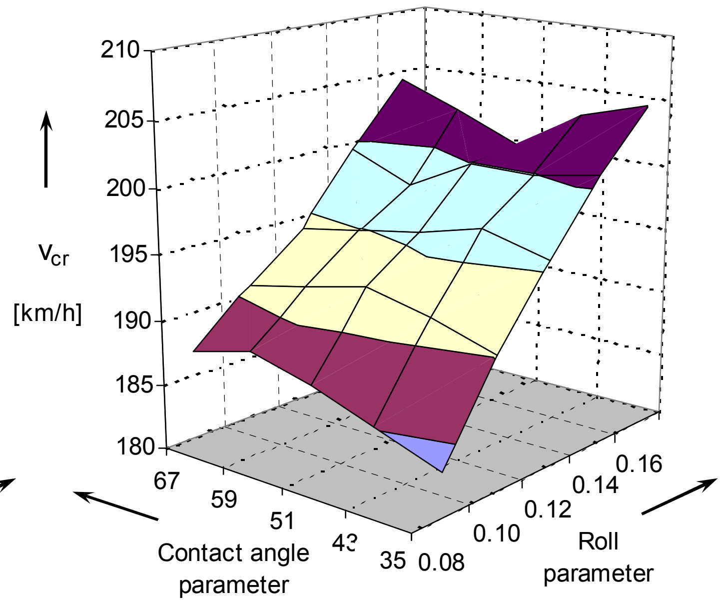


- The linear critical speed can differ even for the same equivalent conicity

Conicity 0.4



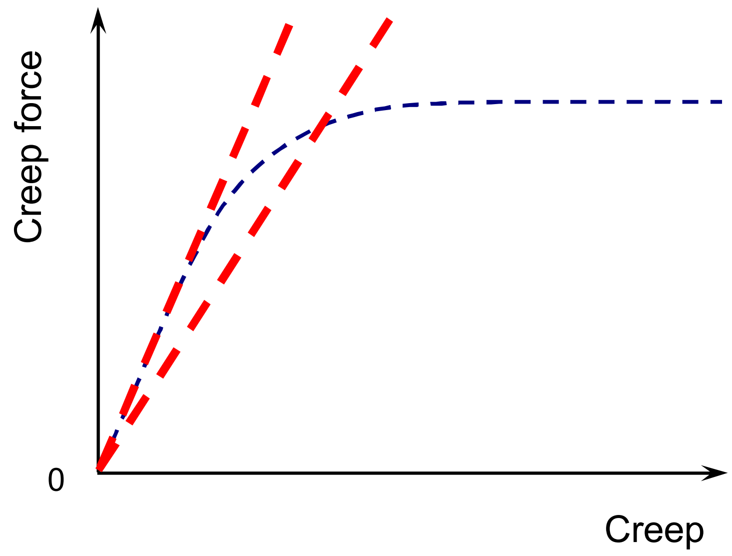
Conicity 0.6



BOMBARDIER

Other parameters influencing linearized analysis

- Creep force law, represented by Kalker's factor
  - ➔ Full creep: 1.0
  - ➔ Reduced creep: 0.67

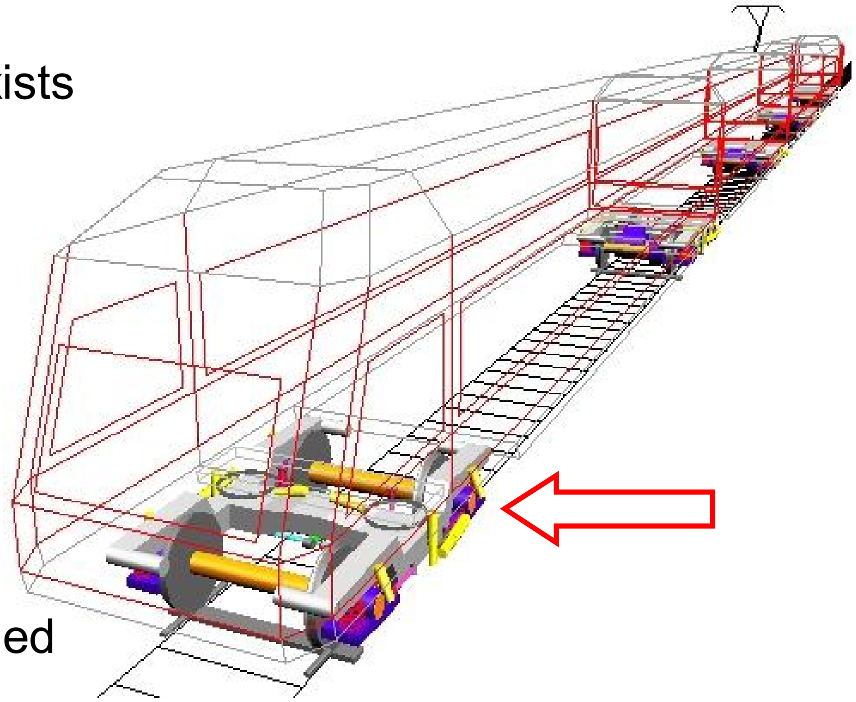


- Minimum damping to ensure stable running
  - ➔ 0 %
  - ➔ 5 %

BOMBARDIER

Overview of non-linear stability calculation methods

- A diversity of non-linear methods exists for stability assessment of railway vehicles dependent on
  - method
  - analysed values
  - criteria



- A four-car articulated vehicle modelled in Simpack
- Four examples of contact geometry wheelset/track with high equivalent conicity and gauge 1435 mm
- Wheel/rail friction coefficient 0.4 (dry)
- Results for the second wheelset

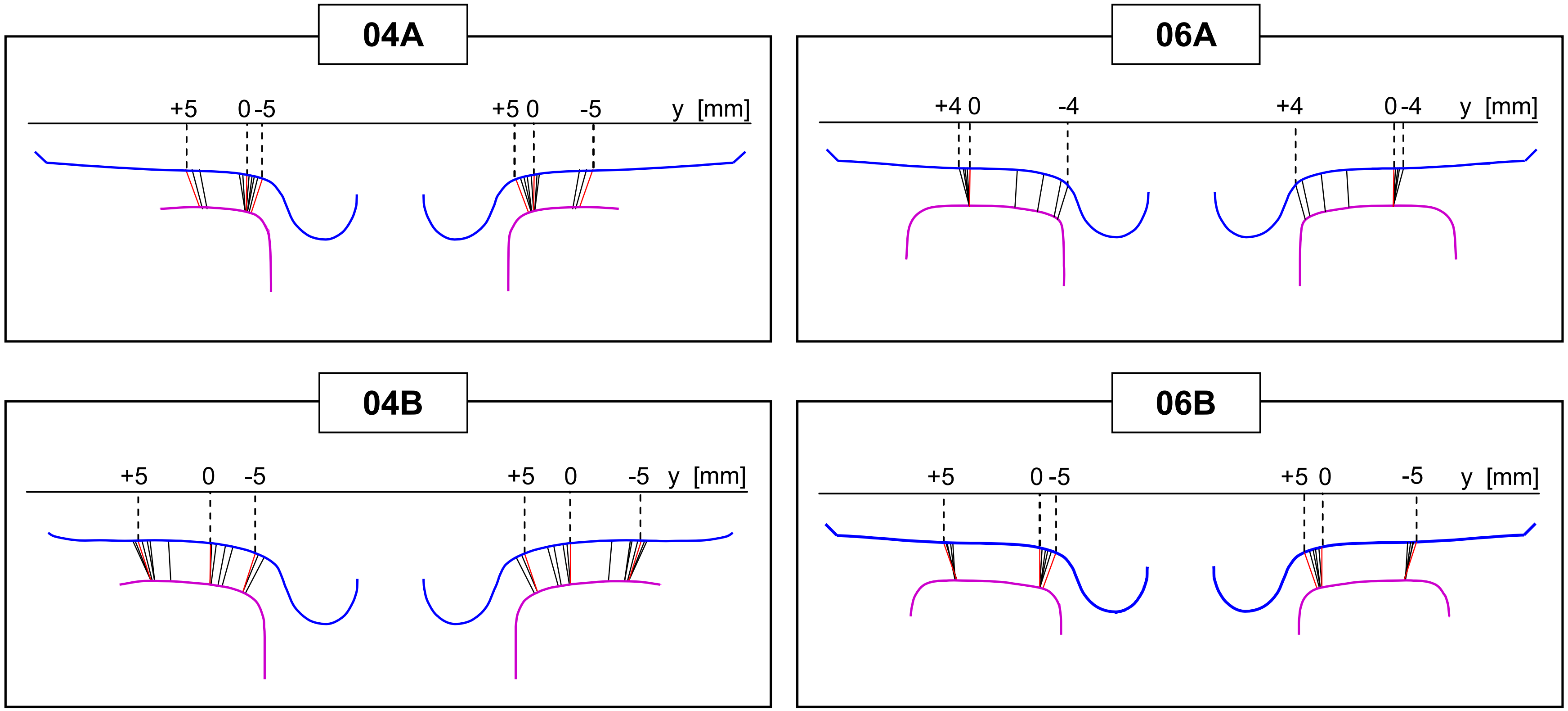
BOMBARDIER

Contact geometry wheelset/track

- In railway standards (UIC Code 518), the contact geometry wheelset/track is described by the equivalent conicity for wheelset lateral amplitude of 3 mm

Equivalent conicity 0.4

Equivalent conicity 0.6

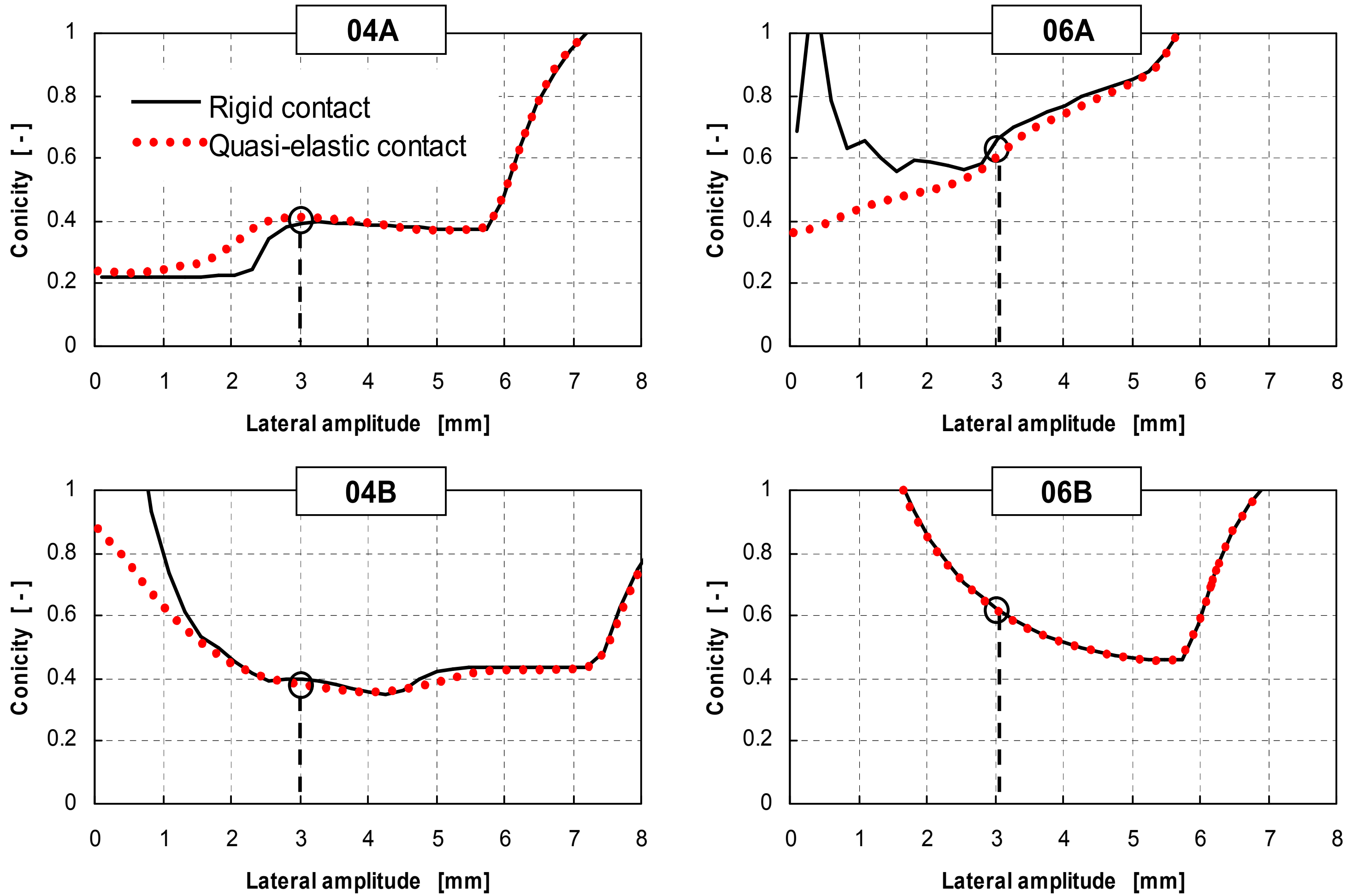


BOMBARDIER

Equivalent conicity as function of wheelset amplitude

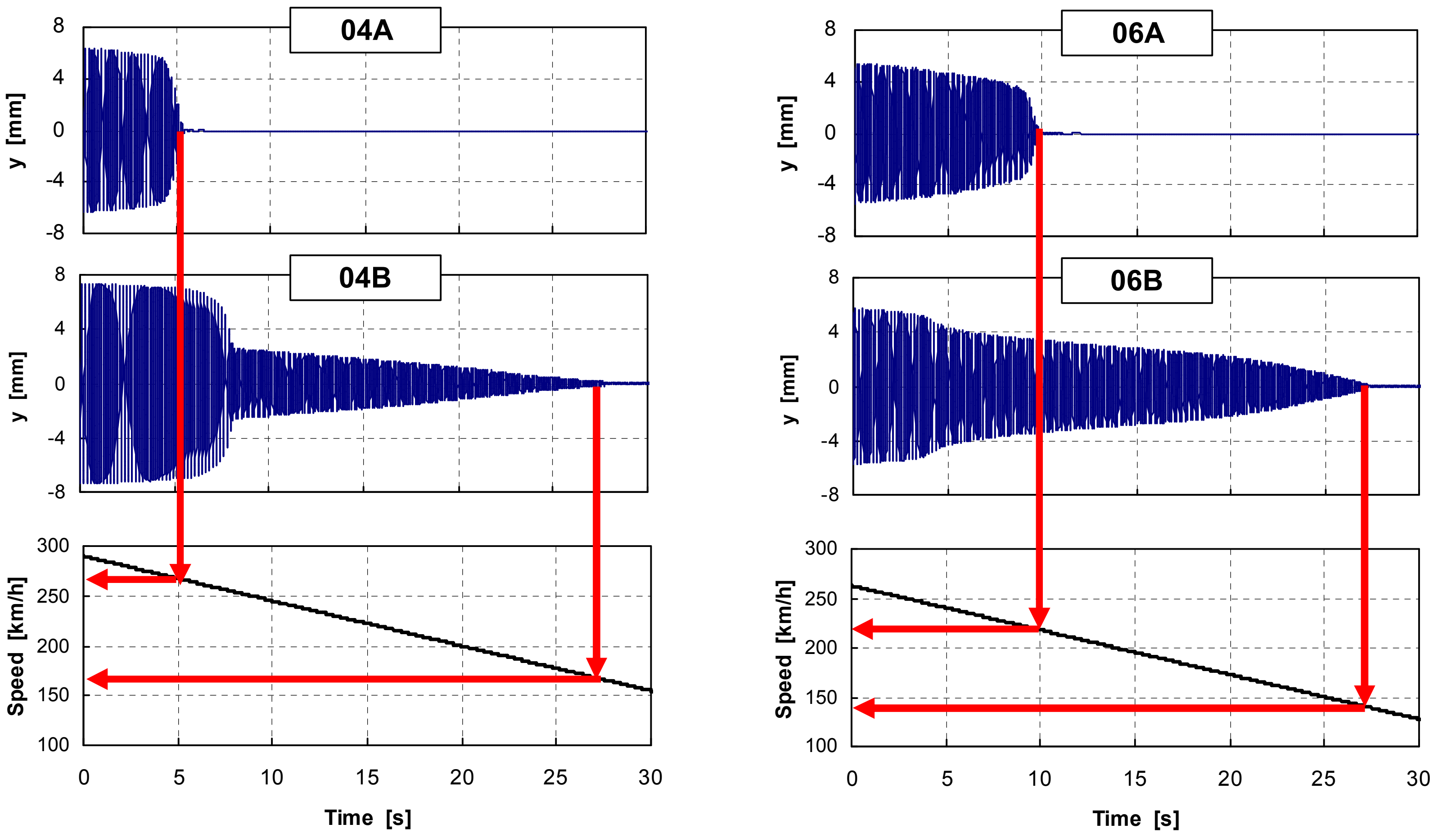
Equivalent conicity 0.4

Equivalent conicity 0.6



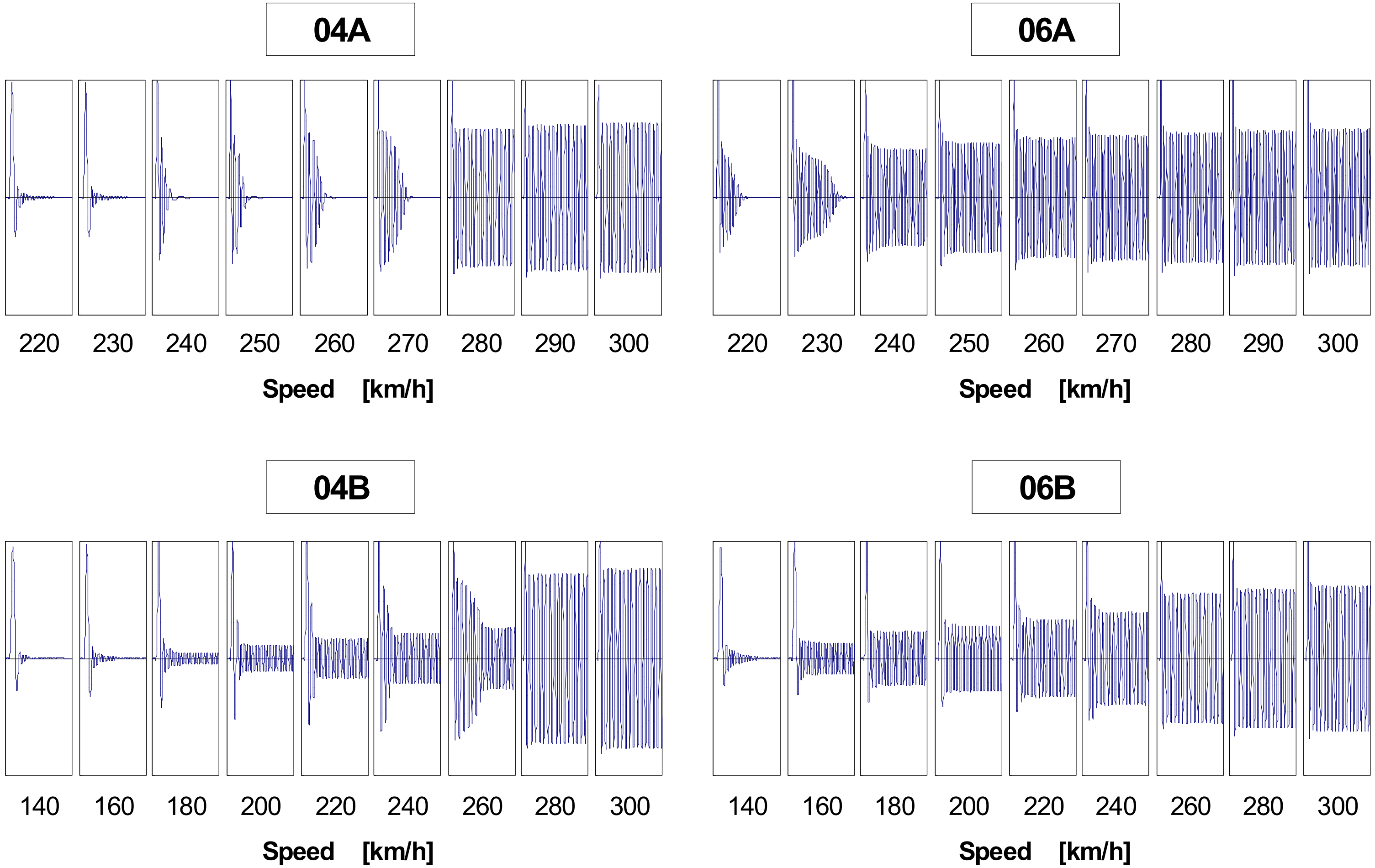
BOMBARDIER

Simulation of run with decreasing speed



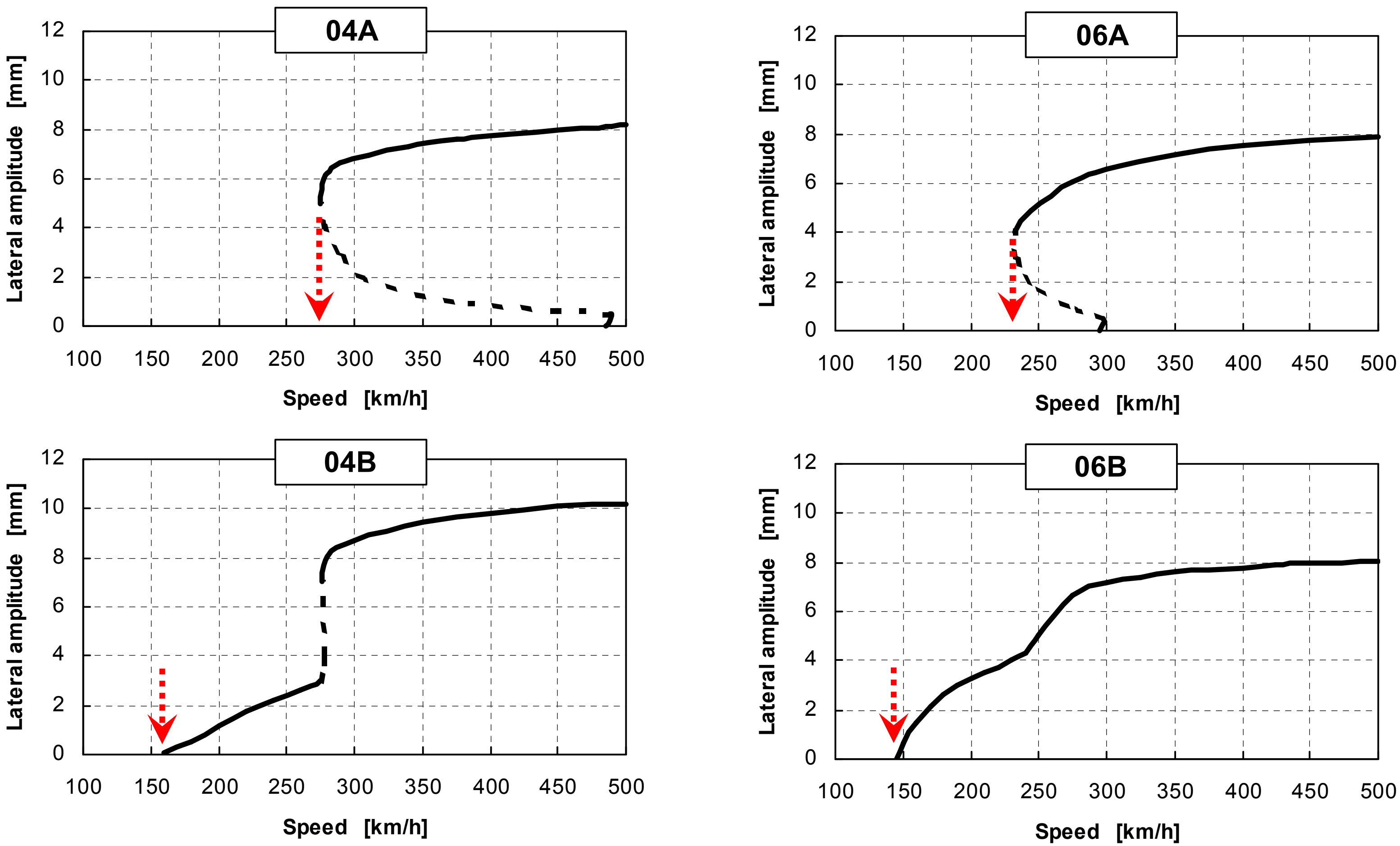
BOMBARDIER

Method with single excitation



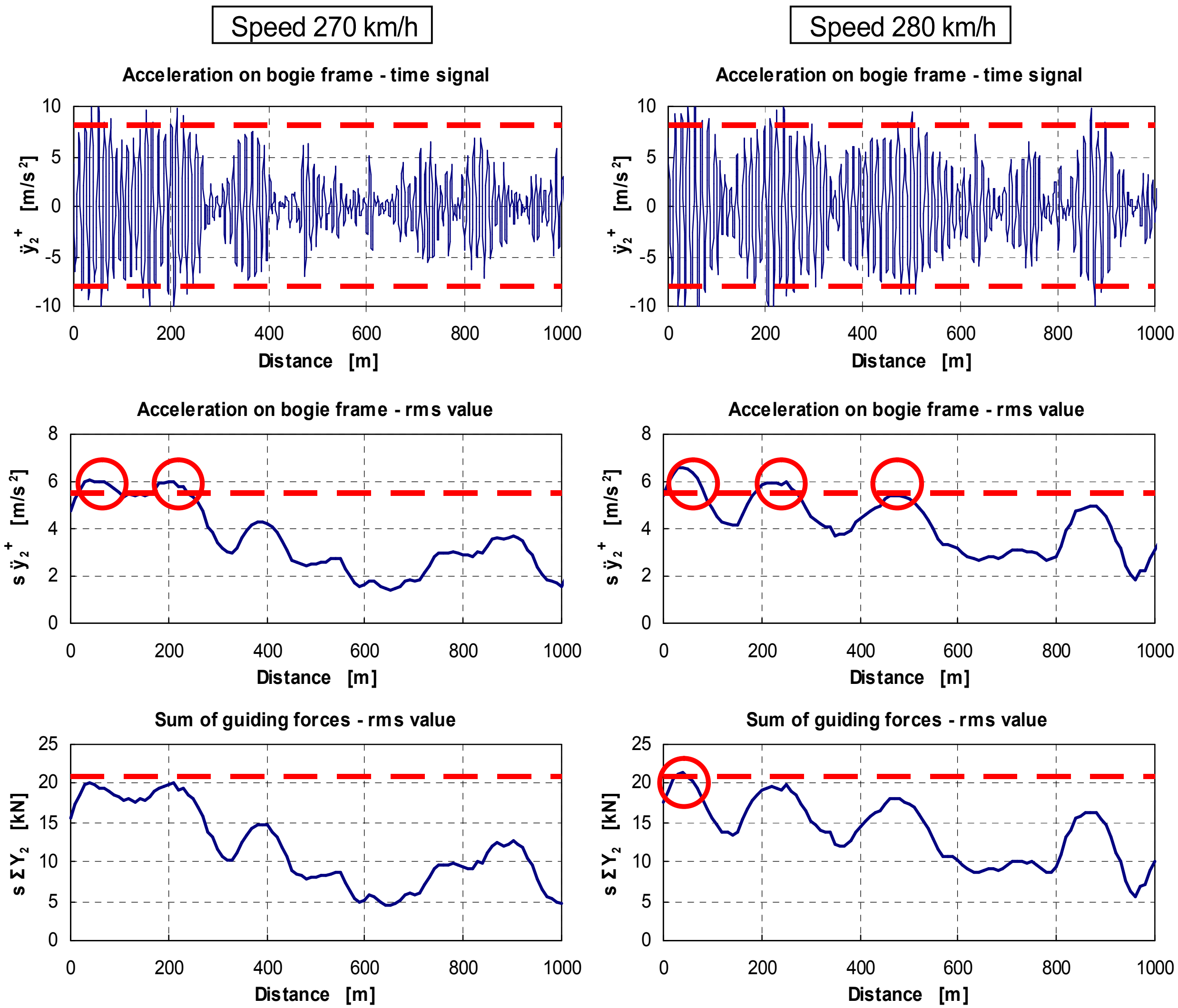
BOMBARDIER

Bifurcation diagrams



BOMBARDIER

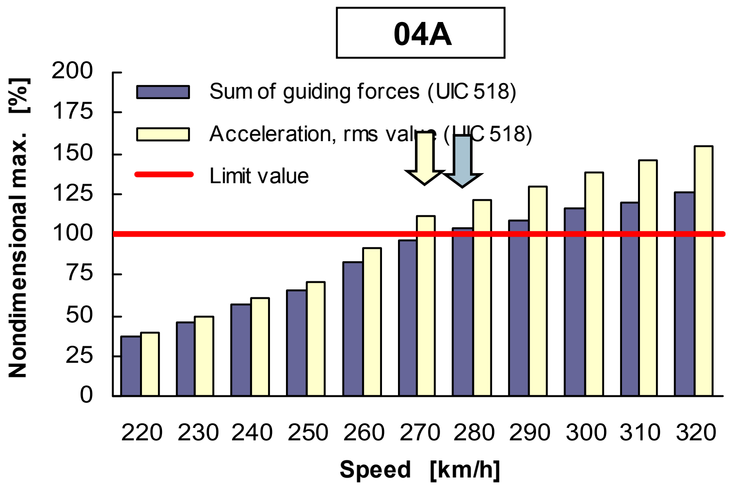
Simulations of run on measured track irregularities

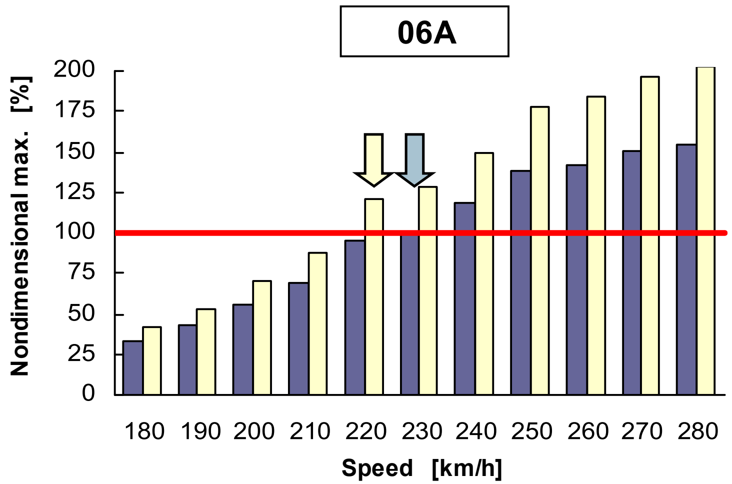


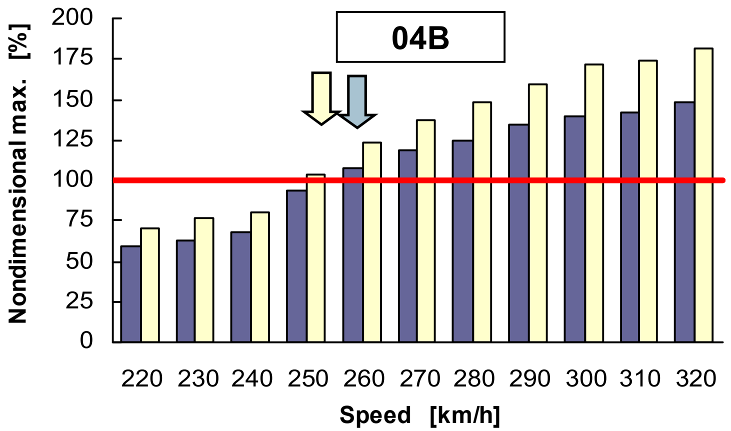
- Lateral acceleration on the bogie frame
- Lateral acceleration, sliding rms value (UIC 518)
- Sum of guiding forces, sliding rms value (UIC 518)

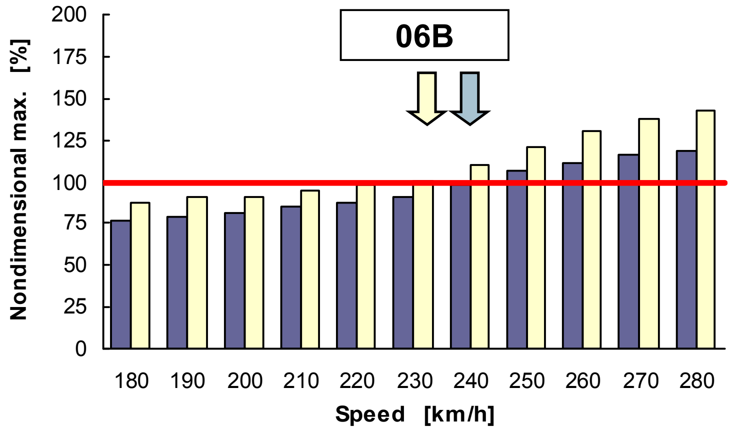
BOMBARDIER

Simulations of vehicle acceptance tests



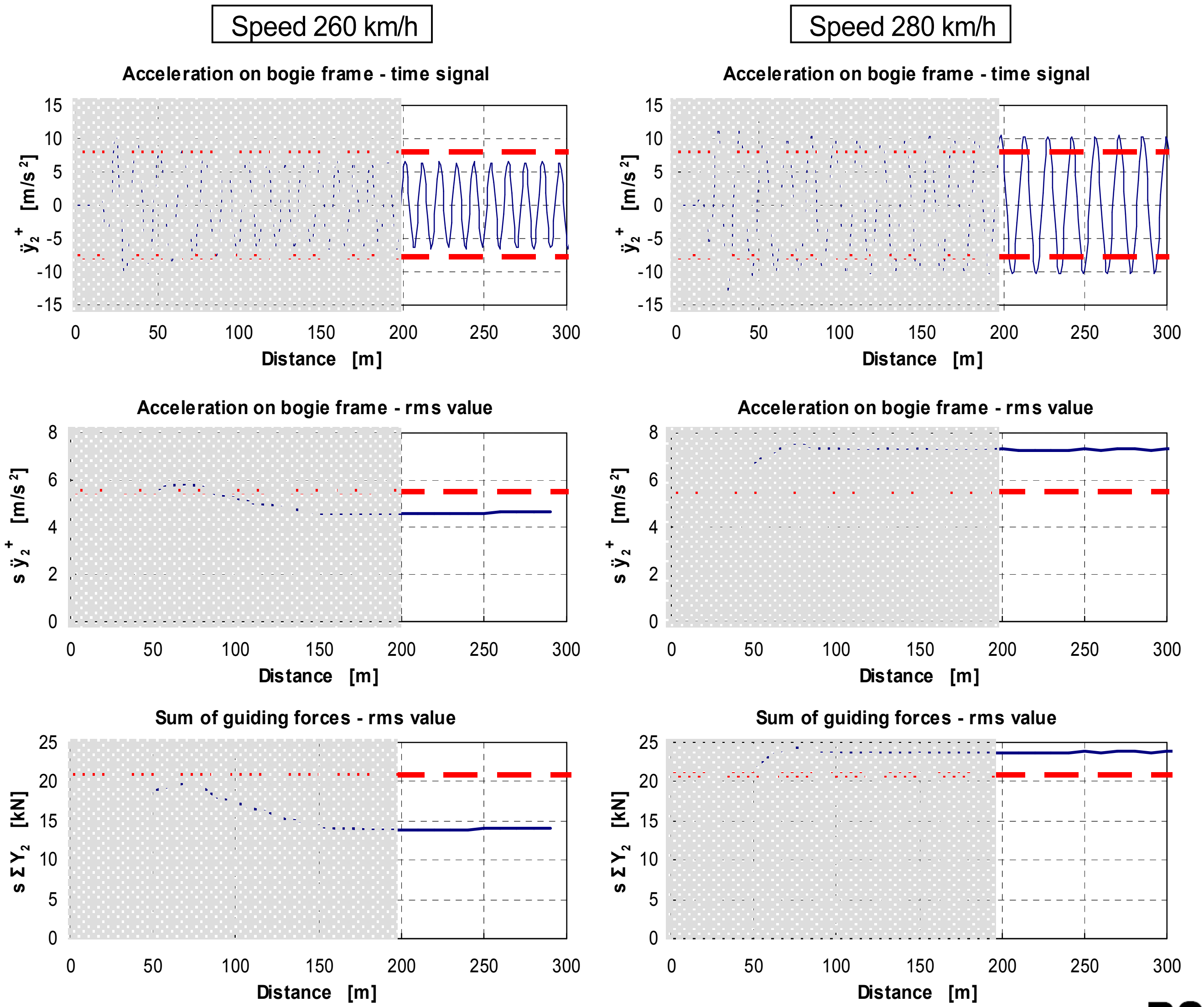






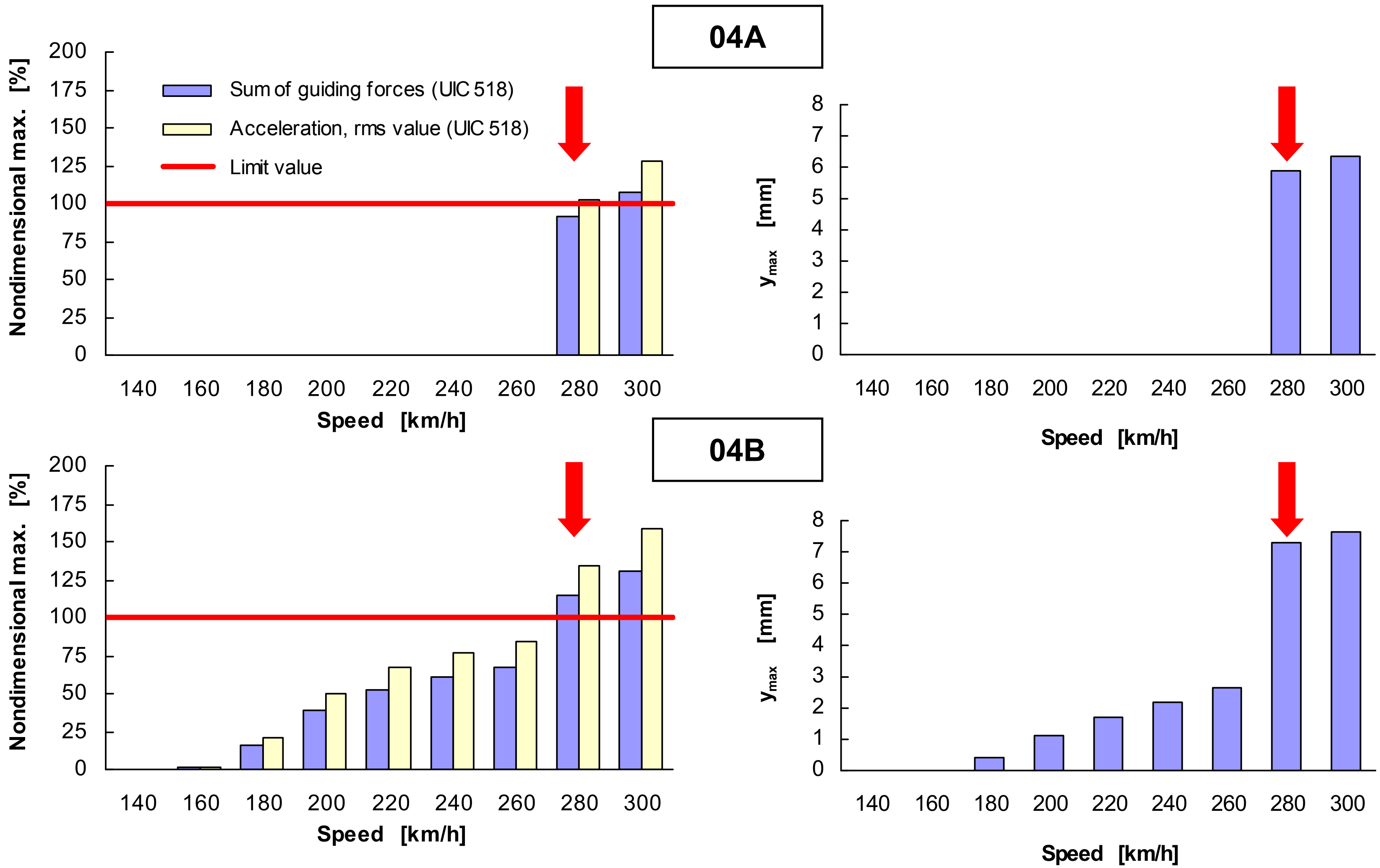
BOMBARDIER

Dynamic behaviour after a single excitation



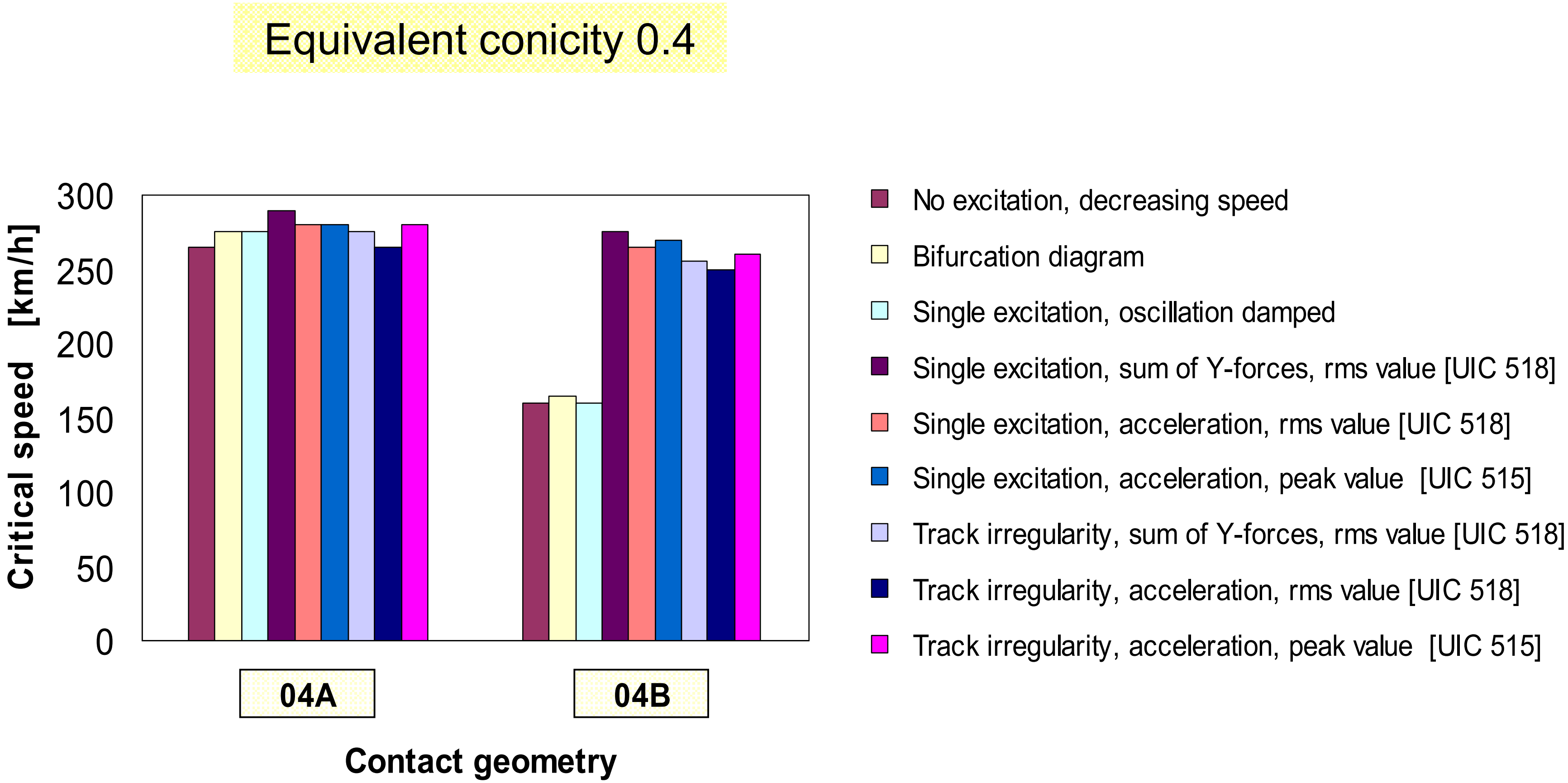
BOMBARDIER

Assessment of behaviour after a single excitation



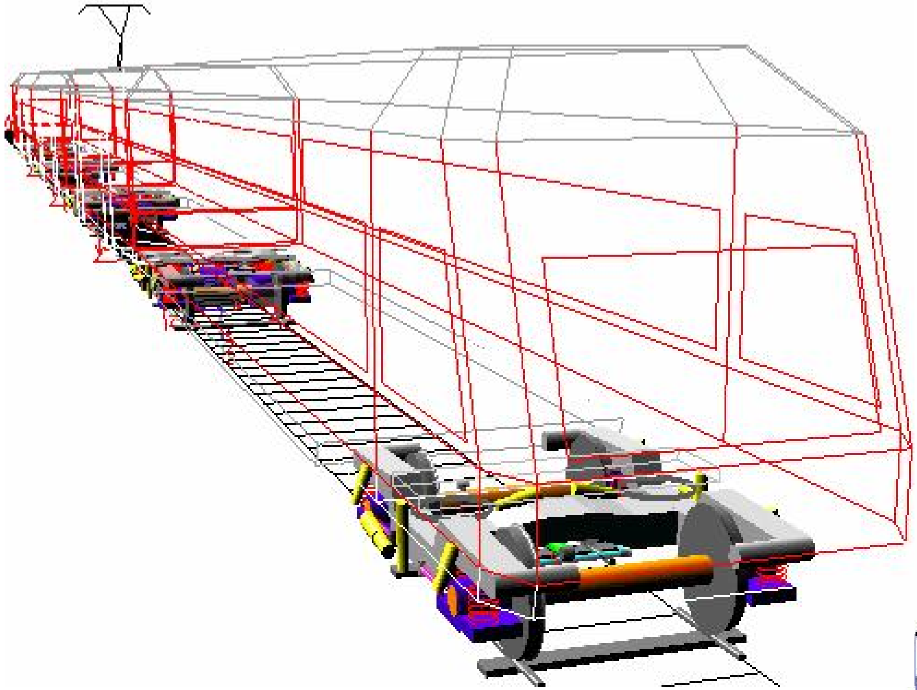
BOMBARDIER

Comparison of resultant critical speeds

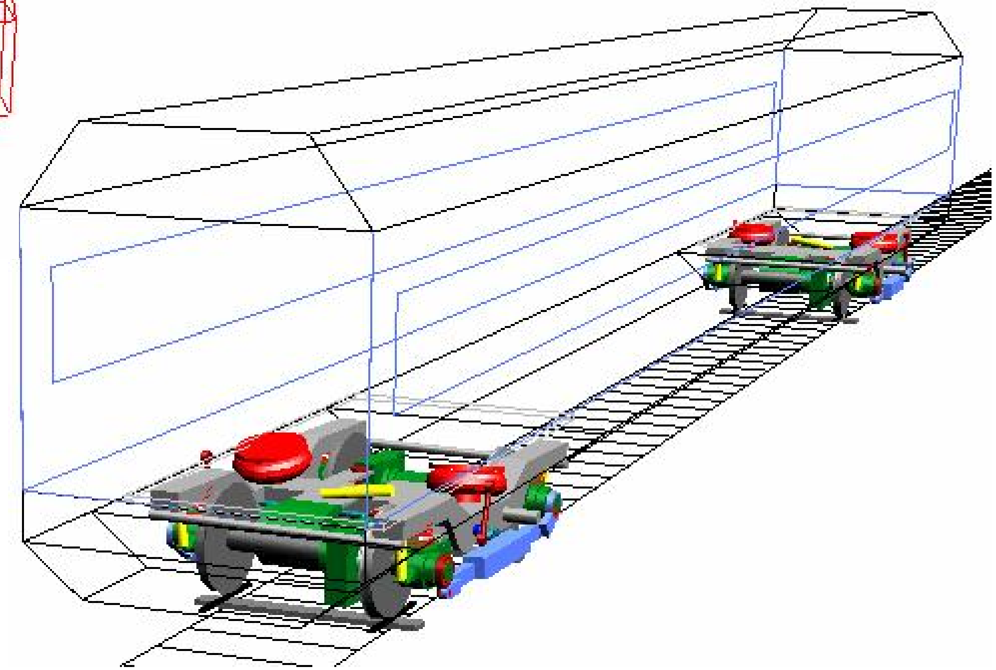


BOMBARDIER

Compared vehicle models



- Vehicle A:
  Four-car articulated vehicle with Jakobs' bogies and yaw dampers

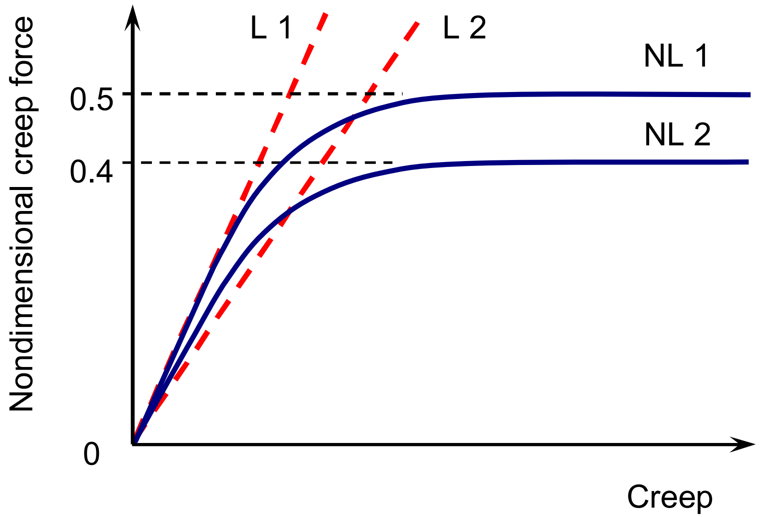


- Vehicle B:
  Conventional passenger coach without yaw dampers

BOMBARDIER

Compared parameters and conditions

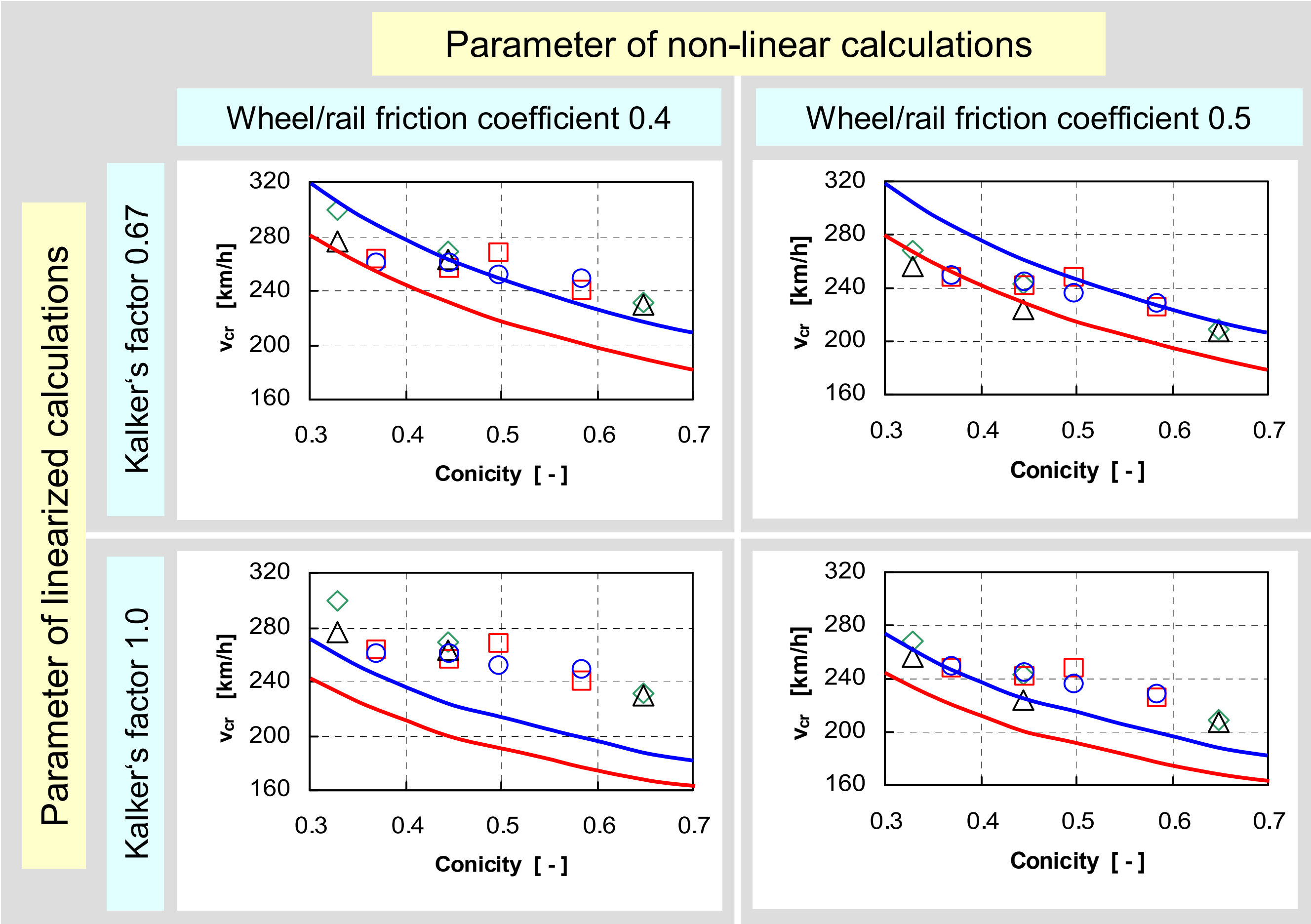
- Quasi-linear analyses
  - Kalker's factor 0.67 and 1.0
  - Minimum damping 0% and 5%



- Non-linear analyses
  - Wheel/rail friction coefficient 0.4 and 0.5
  - Wheel/rail pairings to set up the specified conicity by
    - altering the track gauge
    - wearing of the rail profile
  - Method applied
    - damping behaviour after a single lateral disturbance
    - run on track with measured irregularities, criterion sum of guiding forces according to UIC 518

BOMBARDIER

Comparison of resultant critical speeds – Vehicle A



Variation of rail profiles:

Variation of gauge:

Non-linear calculations:

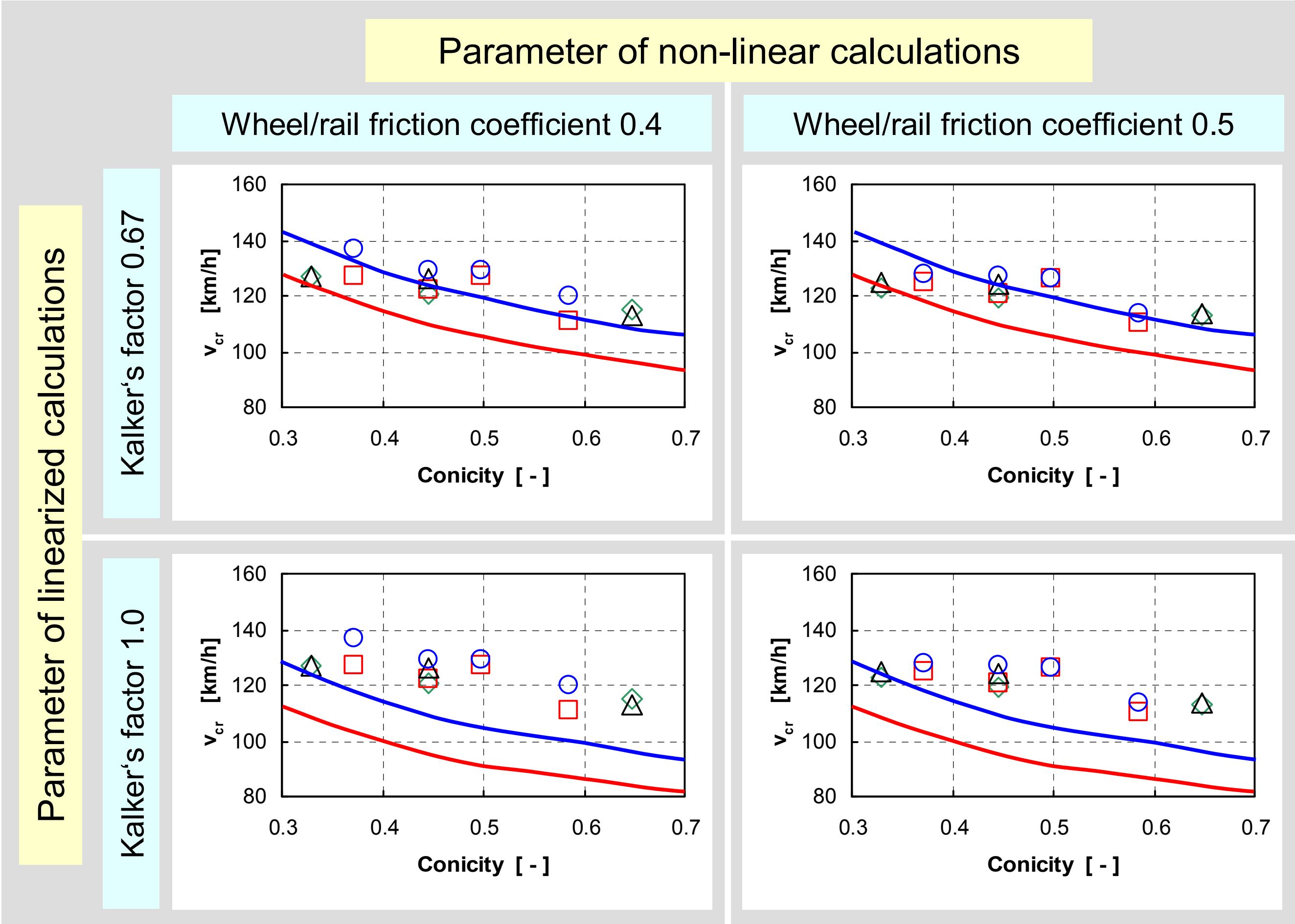
- ◇ Criterion: Damping after a single excitation
- △ Criterion: Sum of Y-forces (UIC 518)
- □ Criterion: Damping after a single excitation
- ○ Criterion: Sum of Y-forces (UIC 518)

Linearized calculations:

- Minimum damping 0%
- Minimum damping 5%

BOMBARDIER

Comparison of resultant critical speeds – Vehicle B



Variation of rail profiles:

Non-linear calculations:
◇ Criterion: Damping after a single excitation
△ Criterion: Sum of Y-forces (UIC 518)

Variation of gauge:

□ Criterion: Damping after a single excitation
○ Criterion: Sum of Y-forces (UIC 518)

Linearized calculations:
Minimum damping 0%
Minimum damping 5%

Conclusion

- The equivalent conicity is not a sufficient input for an exact stability assessment.
- Even for the same equivalent conicity:
  - the resultant linear critical speeds can vary dependet on other linearisation parameters, Kalker's factor and residual damping,
  - the resultant nonlinear critical speeds can vary dependet on the wheel/rail contact geometry, friction coefficient, calculation method and criteria applied.
- For the application of the linearized stability calculations during vehicle design conservative parameters are recommended in order to be on the safe side in comparison to the non-linear calculations.
- It was demonstrated that, applying the minimum damping of 5% and Kalker's factor 1.0, the critical speeds calculated with quasi-linear wheel/rail contact model are below the non-linear critical speeds.

BOMBARDIER