Suspension Multibody Simulation

Suspension Key Performance Indicator Report

RACE user: RACE Demo
Simulation description: Double Wishbone Demo Simulation - Advanced

Suspension type: Double Wishbone - Advanced

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1 Statement of Non-liability

RACE software provided by race.software is intended as a suspension concept development tool. It is designed to help you to understand the performance of your suspension system. This report contains information on the performance of a suspension system as specified by the inputs you have supplied to the RACE software programme. Race.software has no control over the inputs chosen by you and takes no reponsibility for the performance of your suspension system. You are the owner of your suspension system and you are reponsible for its performance. The results of the RACE software should be used only to improve your understanding of its operation, not as a guaranteed prediction of how it will perform. It is your reponsibility as the user of RACE software to interpret the results it provides and to make your own judgement as to how your suspension will perform in real life.

2 RACE Kinematics and Compliance Analysis

RACE is a specialist multibody dynamics software for virtual suspension Kinematics and Compliance (K&C) testing. The K&C analysis is done on a complete front or rear suspension model (half car model/axle model). The K&C test cases are described in the sections below. The test inputs are simplified representations of the motion and loading a suspension system is subject to during its operation in roll, cornering, braking and traction.

The simplified inputs allow the force-response interactions of the suspension system to be measured, understood and ultimately tuned. The key to good suspension design is to develop the suspension system to move (kinematics) and deform (compliance) in a way that gives the driver confidence and delivers controlled, predictable vehicle behaviour.

2.1 RACE Kinematics tests

- **Vertical Motion**: ±50 mm parallel wheel travel.
- **Roll Motion**: ±50 mm opposite wheel travel. The test is run with the anti-roll bar connected (RACE Advanced and RACE Pro only).
- **Steering Input**: ±50 mm steering rack travel in RACE Standard. The steering rack travel is user defined in RACE Advanced and RACE Pro.

2.2 RACE Compliance tests

- **Lateral Force**: ±3000 N lateral load applied at the tyre contact patch. The loads are applied in-phase (load applied to left and right wheel in the same direction) and anti-phase (load applied to left and right wheel in opposite directions). The tests are run with the load applied at the contact patch (0mm trail) and with the load applied 30mm behind the contact patch (30mm trail). (Anti-phase tests are run in RACE Pro only)
- **Braking Force**: ±3000 N longitudinal load applied at the tyre contact patch. The test is run with the load applied to both wheels and also with the load applied to the left wheel only. (Single wheel test is run in RACE Pro only)
- **Traction Force**: ±3000 N longitudinal load applied at the wheel centre. The test is run with the load applied to both wheels and also with the load applied to the left wheel only. (Single wheel test is run in RACE Pro only)
- **Tyre Aligning Torque**: ±300 Nm torque applied at the tyre contact patch. The moments are applied in-phase (moment applied to left and right wheel in the same direction) and anti-phase (moment applied to left and right wheel in opposite directions). (Anti-phase test is run in RACE Pro only)

3 Simulation Details

- **Simulation description:** Double Wishbone Demo Simulation - Advanced

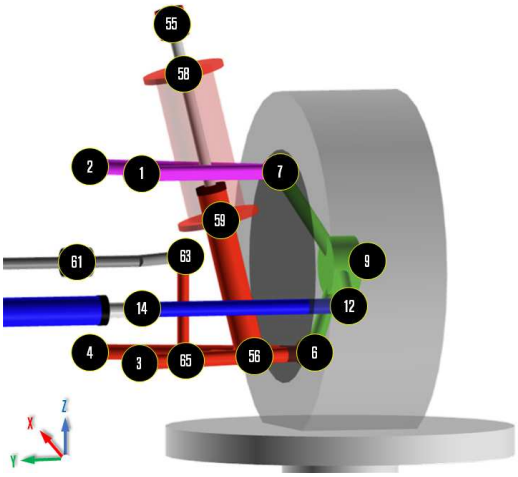

Figure 1: Suspension hardpoint numbering convention

Table 1: Suspension hardpoint co-ordinates

Hardpoint	X (mm)	Y (mm)	Z (mm)
p1	1200.00	-400.00	1303.00
p2	1500.00	-400.00	1297.00
p3	1200.00	-400.00	1000.00
p9	1350.00	-750.00	1100.00
p4	1500.00	-400.00	1000.00
p6	1350.00	-700.00	1000.00
p7	1380.00	-650.00	1330.00
p12	1200.00	-720.00	1053.00
p14	1200.00	-430.00	1050.00
p55	1350.00	-450.00	1500.00
p56	1350.00	-640.00	1000.00
p58	1350.00	-450.00	1500.00
p59	1350.00	-565.00	1200.00
p61	1600.00	-400.00	1100.00
p63	1430.00	-550.00	1100.00
p65	1430.00	-550.00	1000.00

Table 2: Suspension joint types

Joint	Type	Key stiffnesses	Joint attached to
p1	Advanced joint	*Click to view joint stiffness*	Chassis
p2	Advanced joint	*Click to view joint stiffness*	Chassis
p3	Advanced joint	*Click to view joint stiffness*	Chassis
p4	Advanced joint	*Click to view joint stiffness*	Chassis
p6	Advanced joint	*Click to view joint stiffness*	Knuckle
p7	Advanced joint	*Click to view joint stiffness*	Knuckle
p12	Advanced joint	*Click to view joint stiffness*	Knuckle
p14	Advanced joint	*Click to view joint stiffness*	Steering rack
p19	Wheel bearing	Conical 10 kNm/Deg	Wheel hub
p55	Advanced joint	*Click to view joint stiffness*	Chassis
p56	Advanced joint	*Click to view joint stiffness*	Lower control arm
p58	Spring upper	Rigid attachment	Damper rod (coilover)
p59	Spring lower	Rigid attachment	Damper tube (coilover)
p63	Ball joint	Radial 50 kN/mm; Axial 50 kN/mm	Antiroll bar
p65	Ball joint	Radial 50 kN/mm; Axial 50 kN/mm	Lower control arm
p72	Rod guide	Conical 5 kNm/Deg	Damper rod

Table 3: Suspension parameters

Parameter	Value	Unit
Spring rate	30.00	N/mm
Spring preload	5000	N
Arb rate	10000.0	Nmm/Deg
Tyre loaded radius	300.0	mm
Wheelbase	2200.0	mm
Steering rack travel	55.0	mm
Ride height	0.0	mm

Table 4: RACE simulation stats

Phase	CPU Time (s)	Status
Pre-processing	70.6	Complete

Phase	CPU Time (s)	Status
Lateral ip30	10.8	Complete
Aligning ip	10.7	Complete
Lateral ip0	10.8	Complete
Traction	11.3	Complete
Braking	11.5	Complete
Vertical	13.4	Complete
Roll	13.7	Complete
Steering	15.0	Complete
Simulation Total	97.2	

Phase	CPU Time (s)	Status
Post-processing	92.0	Complete

4 Suspension Key Performance Indicator Summary

- The suspension KPIs are all calculated for the left wheel of the suspension
- The KPI summary table is split into kinematics and compliance sections
- The kinematics KPIs table can be found in §4.1
- The compliance KPIs table can be found in §4.2
- Click on the KPI name in the tables to link to the KPI graph
- The KPI graphs show the multibody simulation signals plotted to generate the KPI in blue
- The point at which a KPI value was taken from the curve is shown by a red cross
- Where the KPI is calculated from the gradient of the curve, the curve fit is shown by a red line
- Click on the metric unit in the tables to link to the metric sign convention definitions in §6

4.1 RACE Kinematics KPIs

KPI	Unit	Value
ROLL MOTION		
Roll camber	deg/m	-20.4
Roll steer - on centre	deg/m	-2.9
Roll steer - 25mm bump	deg/m	-1.7
Roll steer - 25mm rebound	deg/m	-4.3
Wheel rate in roll	N/mm	37.9
ARB rate at droplink (opposite wheel travel)	N/mm	39.7
ARB rate at droplink (single wheel travel)	N/mm	19.8
STATIC GEOMETRY		
Static camber	deg	-0.02
Static toe	deg	0.03
Track width at contact patch	mm	1500.3
Damper ratio	mm/mm	0.73
Spring ratio	mm/mm	0.73
Spring installed load	N	4845
Spring installed length	mm	326.4
ARB ratio	mm/mm	0.49
STEERING INPUT		
Kingpin inclination - with steer	deg	8.5
Castor angle - with steer	deg	5.1
Castor trail - with steer	mm	17.2
Scrub radius - with steer	mm	20.6
Wheel centre longitudinal offset - with steer	mm	-9.6
Wheel centre lateral offset - with steer	mm	64.2
Steering ratio - on-centre	deg/mm	0.37
Static toelink load	N	-105.9
Steering rack travel - centre to full lock	mm	54.9
Lock angle at full right rack travel	deg	20.2
Lock angle at full left rack travel	deg	-21.1
VERTICAL MOTION		
Bump camber	deg/m	-20.3
Bump steer - on centre	deg/m	-3
Bump steer - 25mm bump	deg/m	-1.7
Bump steer - 25mm rebound	deg/m	-4.3
Bump castor (knuckle rotation)	deg/m	3.7
Kinematic wheel centre recession	mm/m	9.1
Contact patch lateral migration	mm/m	71.9
Wheel rate - on centre	N/mm	28.4
Wheel rate - 25mm bump	N/mm	30.2
Wheel rate - 25mm rebound	N/mm	27

4.2 RACE Compliance KPIs

KPI	Unit	Value
BRAKING FORCE		
Brake steer	deg/kN	-0.007
Braking castor compliance (knuckle rotation)	deg/kN	-0.312
Contact patch longitudinal compliance	mm/kN	2.41
Front anti-dive; Rear anti-lift	N/N	0.011
Front anti-dive; Rear anti-lift	deg	0.6
LATERAL FORCE		
Roll centre height - wheel load variation	N/N	0.072
Camber compliance in-phase 0mm trail	deg/kN	0.054
Contact patch compliance in-phase 0mm trail	mm/kN	0.336
Lateral compliance steer in-phase 0mm trail	deg/kN	-0.026
Lateral compliance steer in-phase 30mm trail	deg/kN	-0.035
Contact patch stiffness in-phase 0mm trail	N/mm	2976
Roll centre height	mm	54
TRACTION FORCE		
Traction steer	deg/kN	0.013
Traction castor compliance (knuckle rotation)	deg/kN	-0.056
Wheel centre longitudinal compliance	mm/kN	0.5
Front anti-lift; Rear anti-squat	N/N	-0.009
Front anti-lift; Rear anti-squat	deg	-0.5
TYRE ALIGNING TORQUE		
Aligning torque toe compliance in-phase	deg/kNm	0.288

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Table 5: Joint parameters: p1

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	10	1	3	50
Axial	0.75	2	4	5
Conical	10000	-	-	-
Torsional	3000	-	-	-

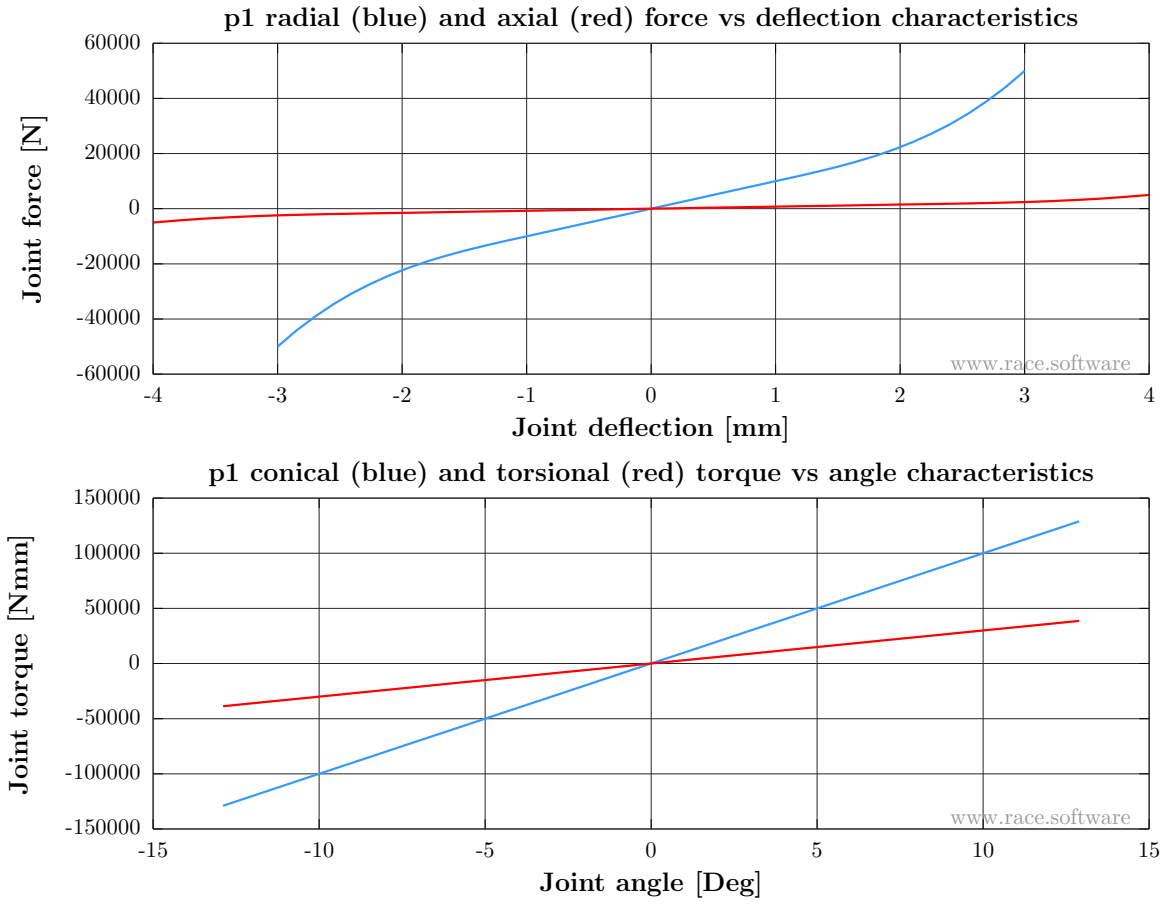

Figure 2: Joint characteristics: p1

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Table 6: Joint parameters: p2

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	10	1	3	50
Axial	0.75	2	4	5
Conical	10000	-	-	-
Torsional	3000	-	-	-

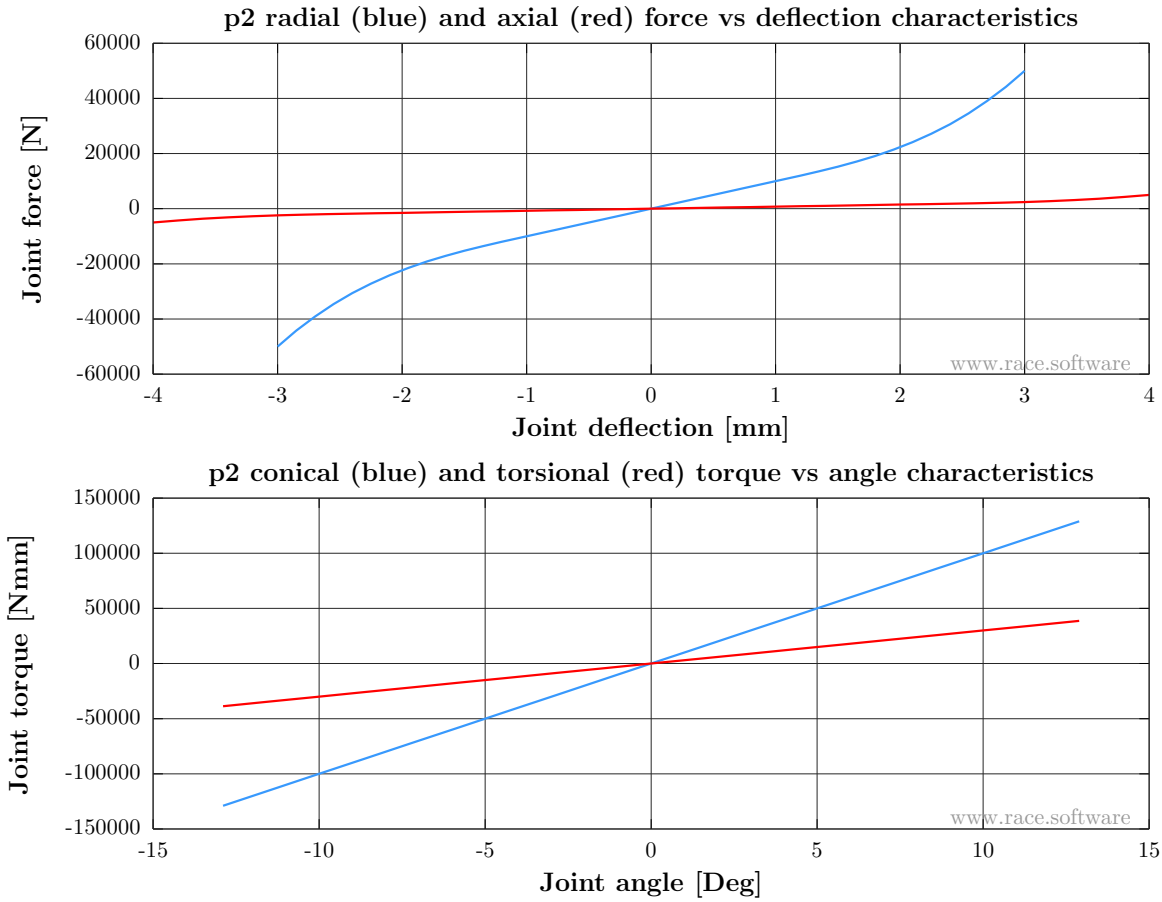

Figure 3: Joint characteristics: p2

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Table 7: Joint parameters: p3

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	16	2	4	75
Axial	0.75	3	5	15
Conical	16000	-	-	-
Torsional	3000	-	-	-

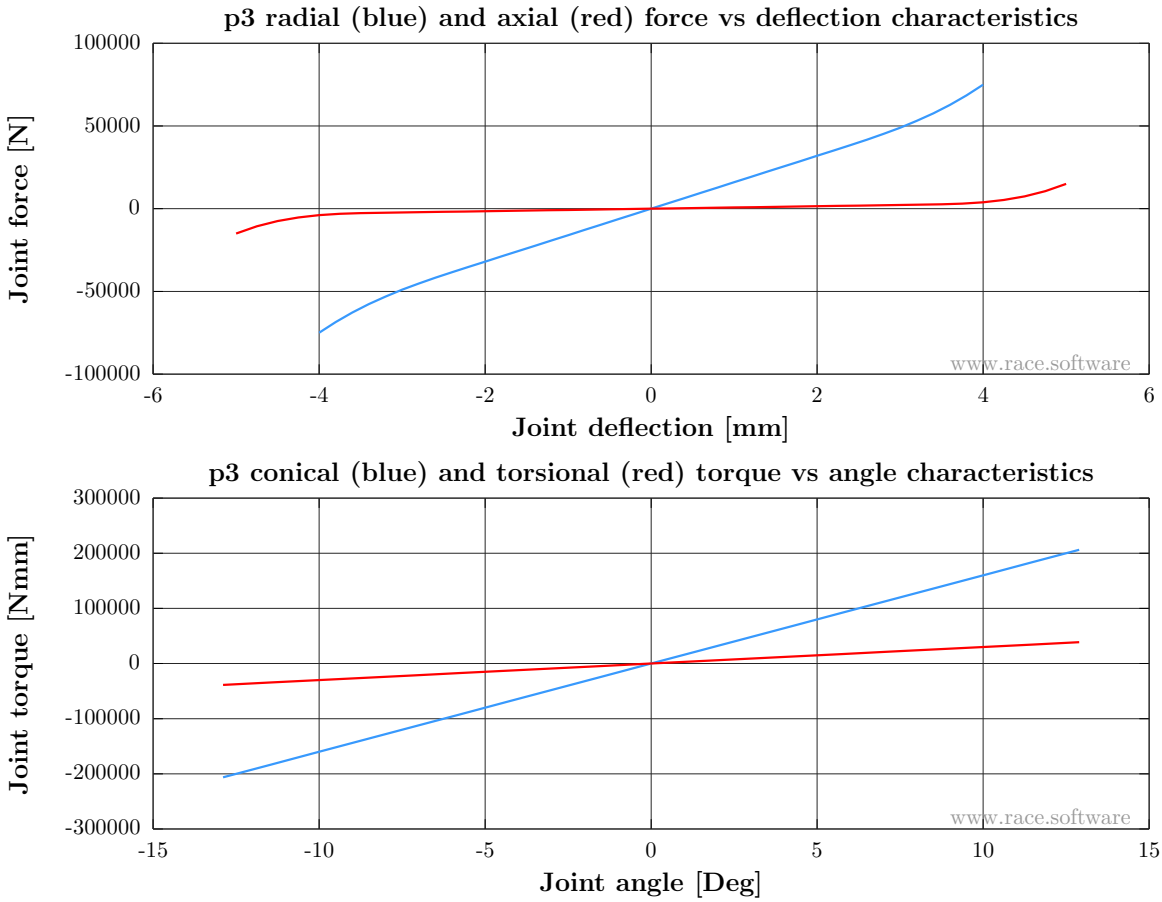

Figure 4: Joint characteristics: p3

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Table 8: Joint parameters: p4

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	16	2	4	75
Axial	0.75	3	5	15
Conical	16000	-	-	-
Torsional	3000	-	-	-

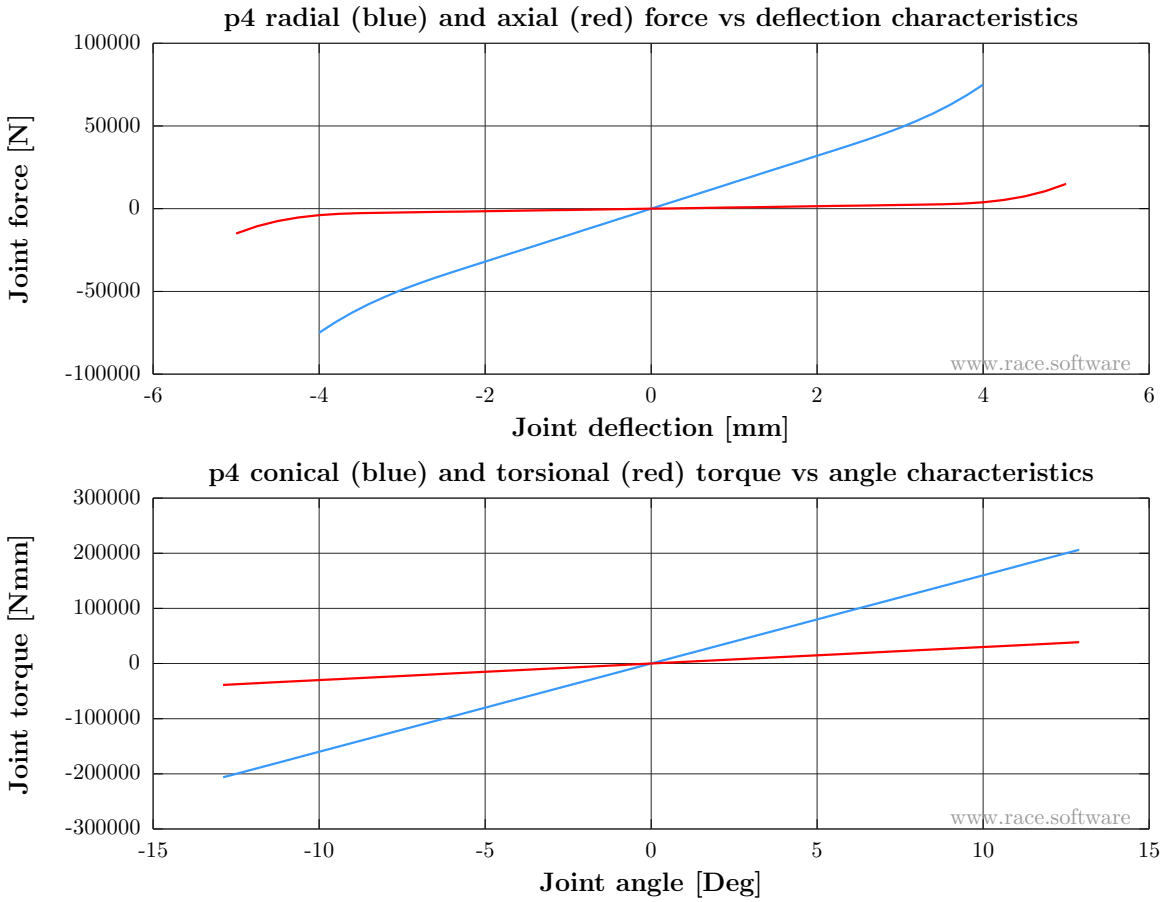

Figure 5: Joint characteristics: p4

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Table 9: Joint parameters: p6

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	50	-	-	-
Axial	50	-	-	-
Conical	0	-	-	-
Torsional	0	-	-	-

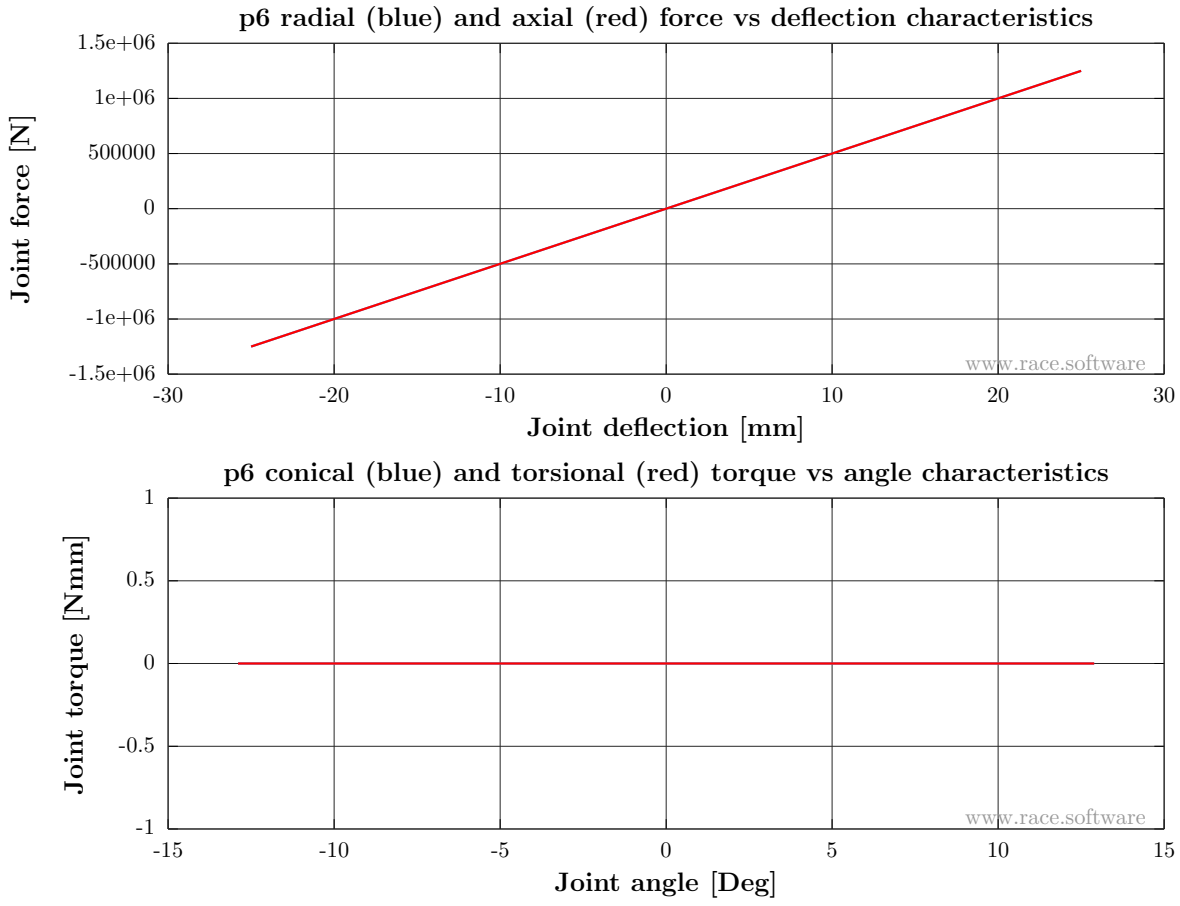

Figure 6: Joint characteristics: p6

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Table 10: Joint parameters: p7

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	50	-	-	-
Axial	50	-	-	-
Conical	0	-	-	-
Torsional	0	-	-	-

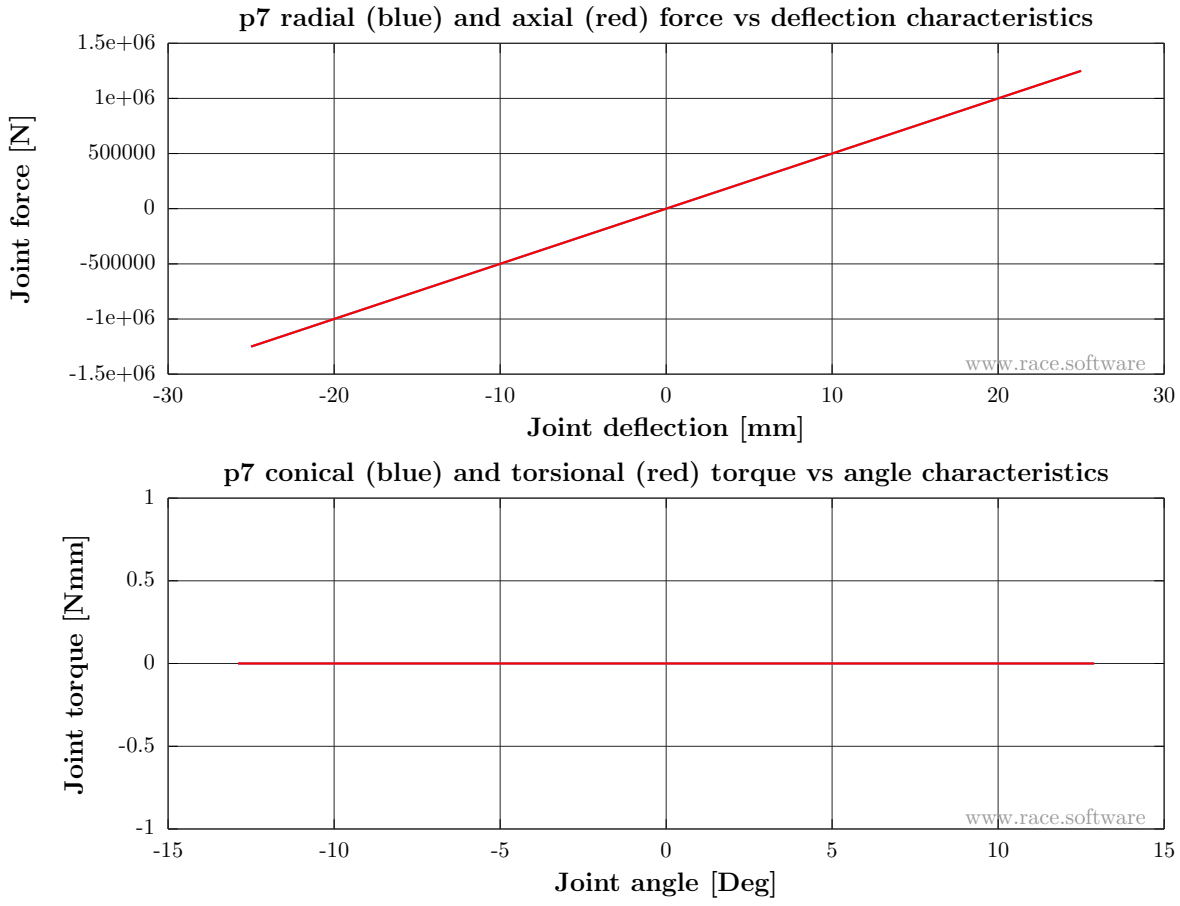

Figure 7: Joint characteristics: p7

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Table 11: Joint parameters: p12

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	50	-	-	-
Axial	50	-	-	-
Conical	0	-	-	-
Torsional	0	-	-	-

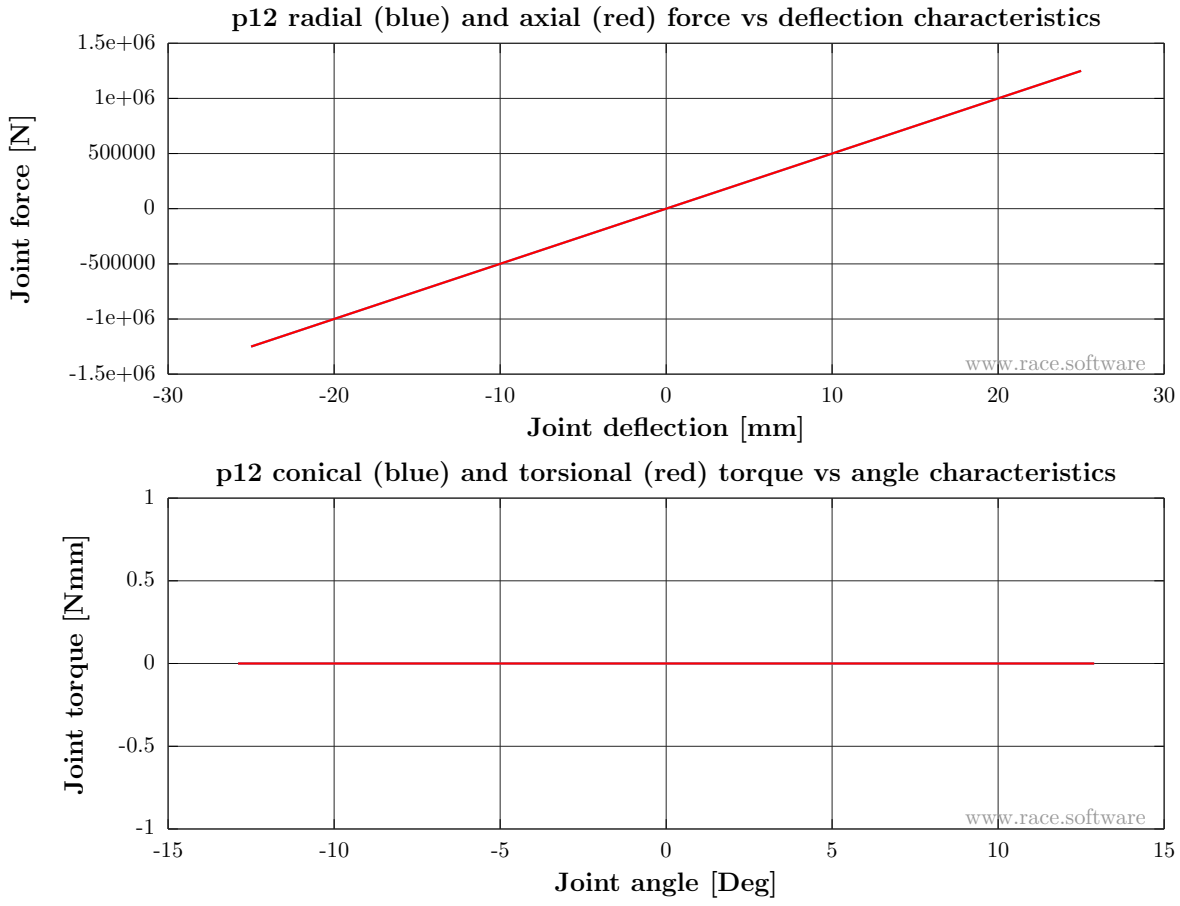

Figure 8: Joint characteristics: p12

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Table 12: Joint parameters: p14

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	50	-	-	-
Axial	50	-	-	-
Conical	0	-	-	-
Torsional	0	-	-	-

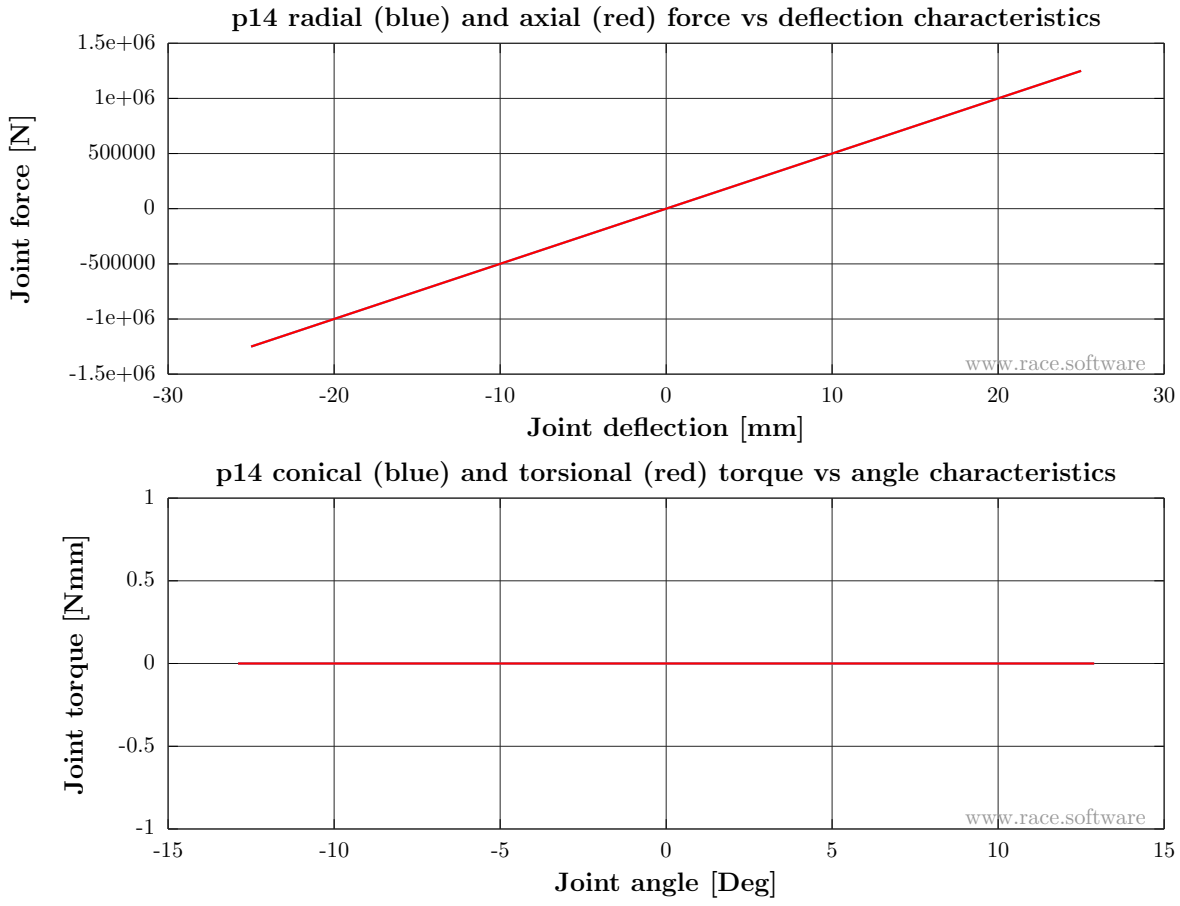

Figure 9: Joint characteristics: p14

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Table 13: Joint parameters: p55

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	3	2	4	15
Axial	0.75	4	6	20
Conical	5000	-	-	-
Torsional	1000	-	-	-

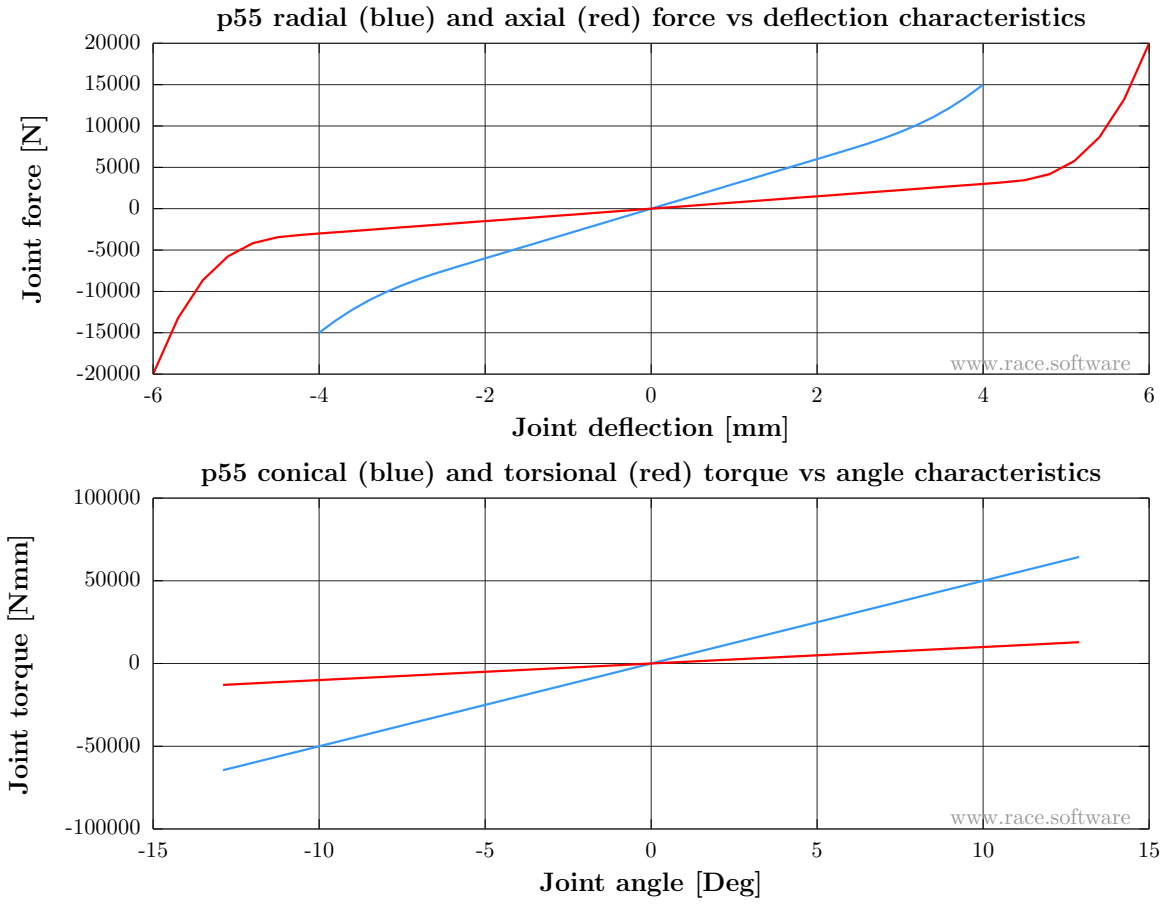

Figure 10: Joint characteristics: p55

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Table 14: Joint parameters: p56

Joint axis	**Linear rate** (kN/mm or Nmm/Deg)	**Linear travel** (mm)	**Total travel** (mm)	**Total force** (kN)
Radial	50	-	-	-
Axial	50	-	-	-
Conical	0	-	-	-
Torsional	0	-	-	-

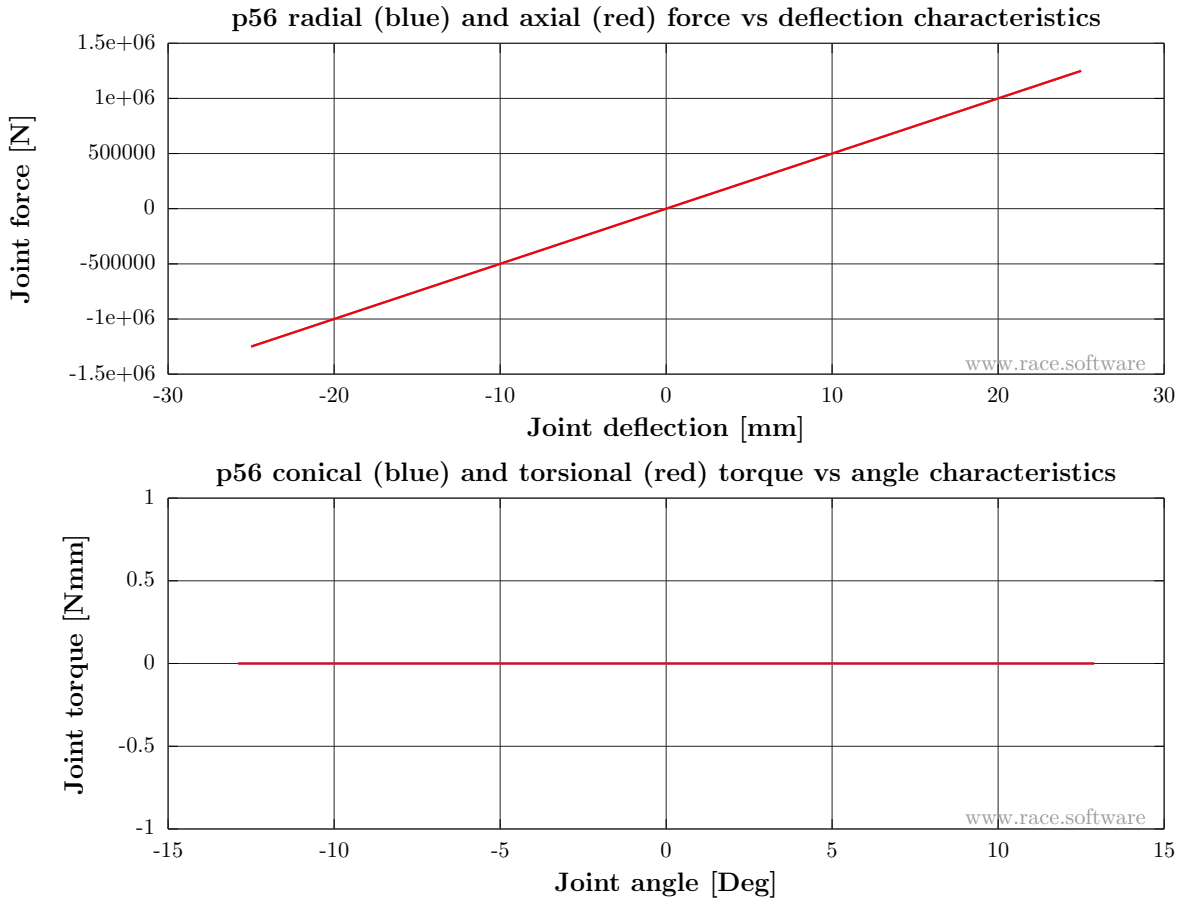

Figure 11: Joint characteristics: p56

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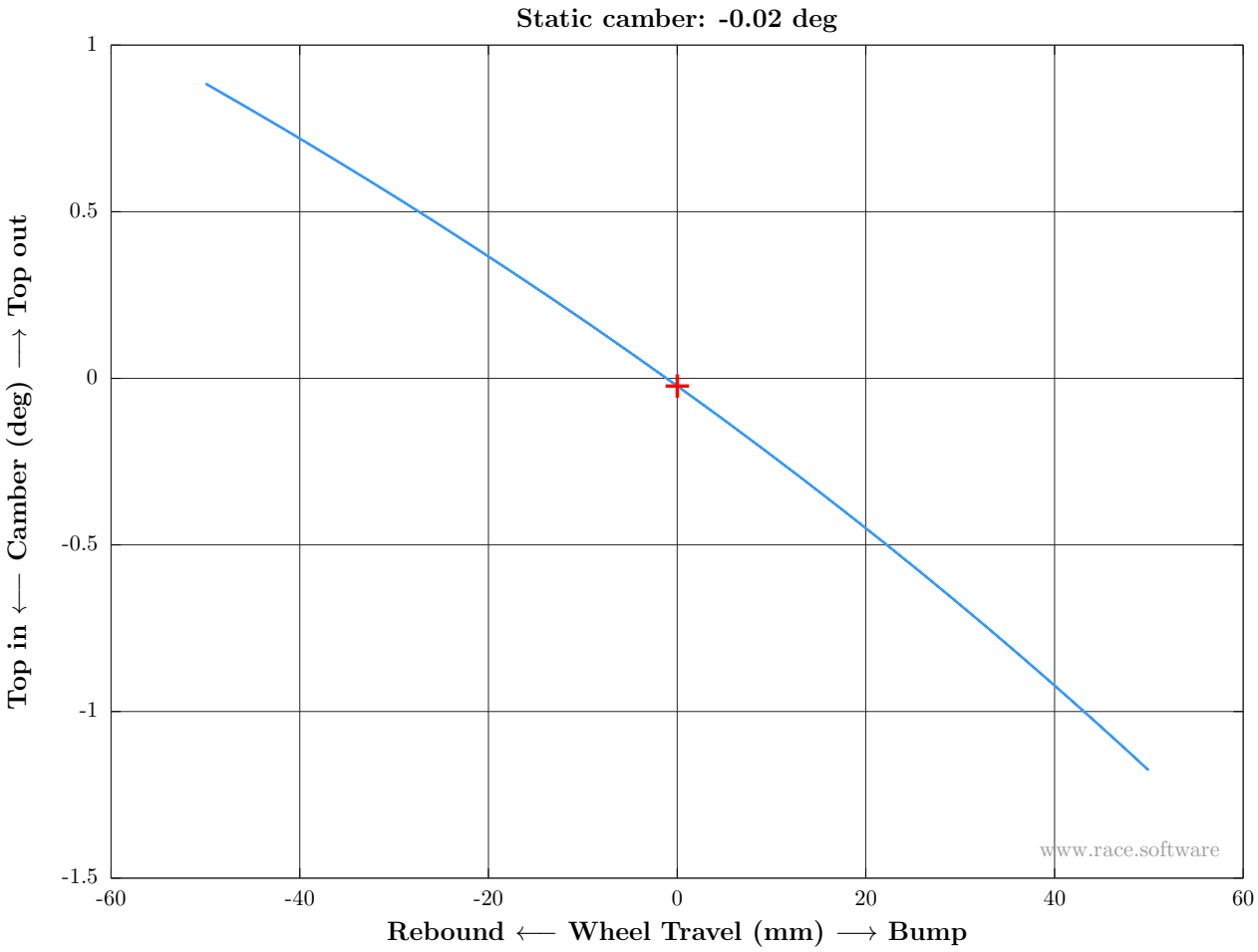

Figure 12: Vertical test: Static camber

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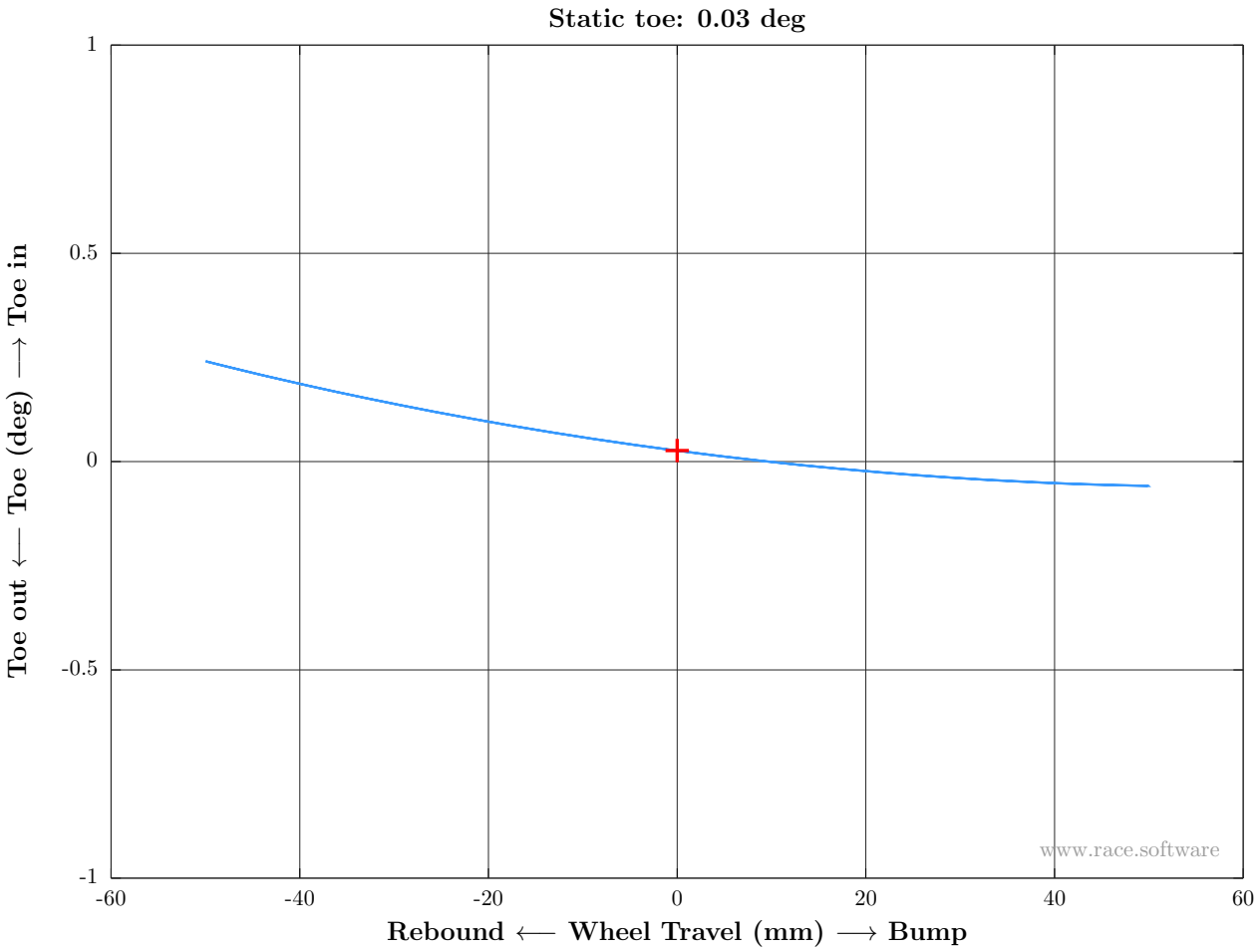

Figure 13: Vertical test: Static toe

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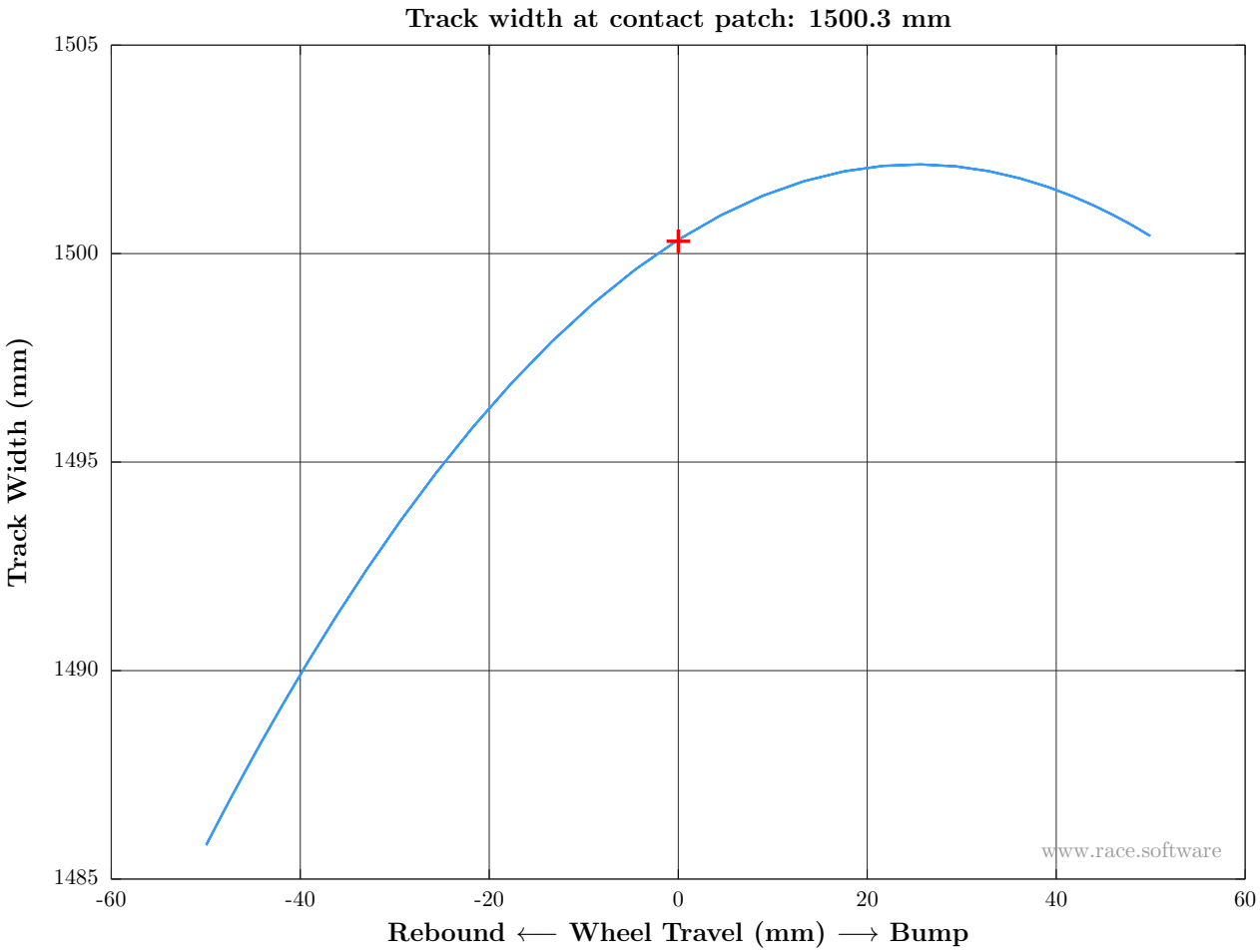

Figure 14: Vertical test: Track width at contact patch

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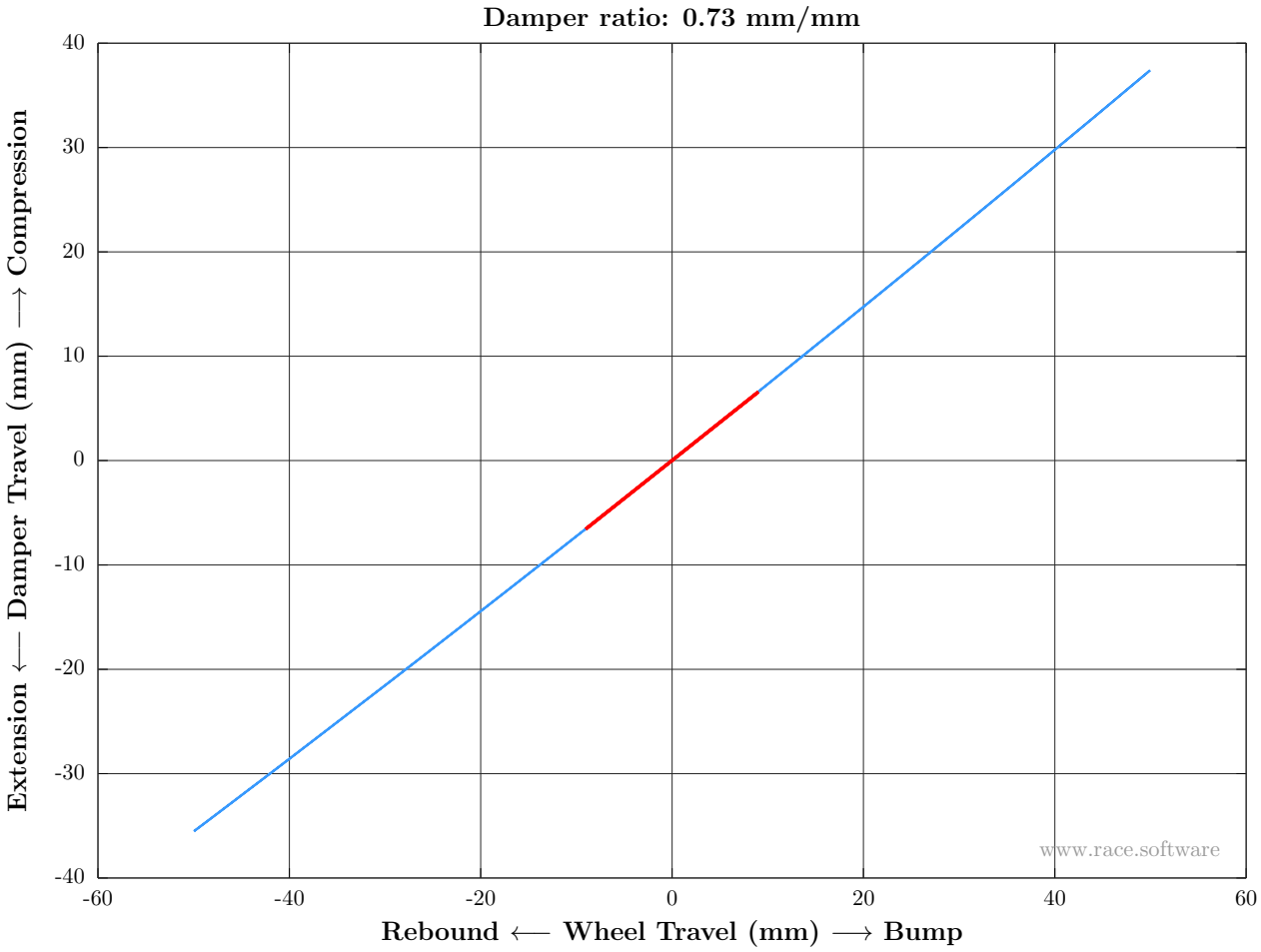

Figure 15: Vertical test: Damper ratio

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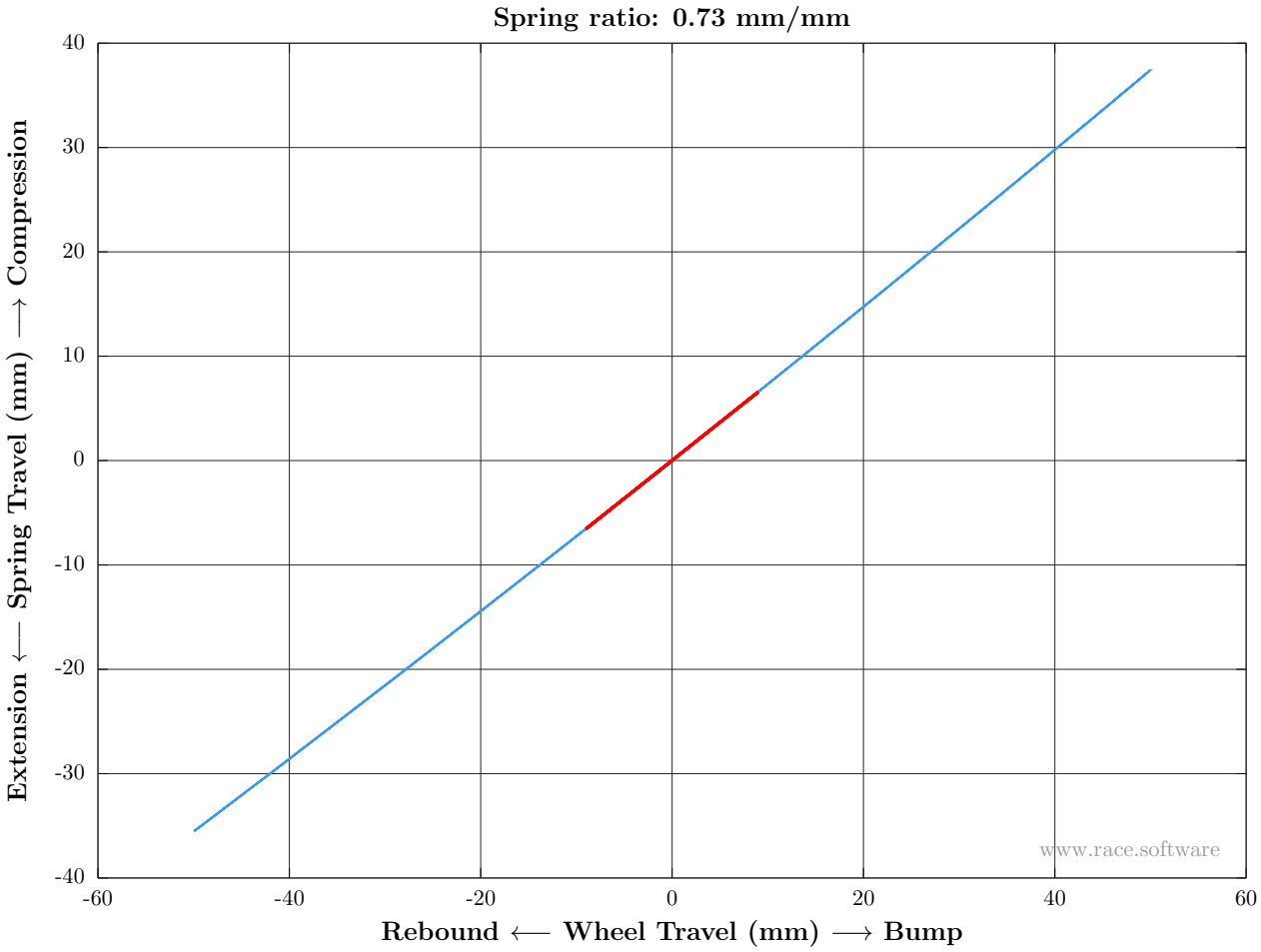

Figure 16: Vertical test: Spring ratio

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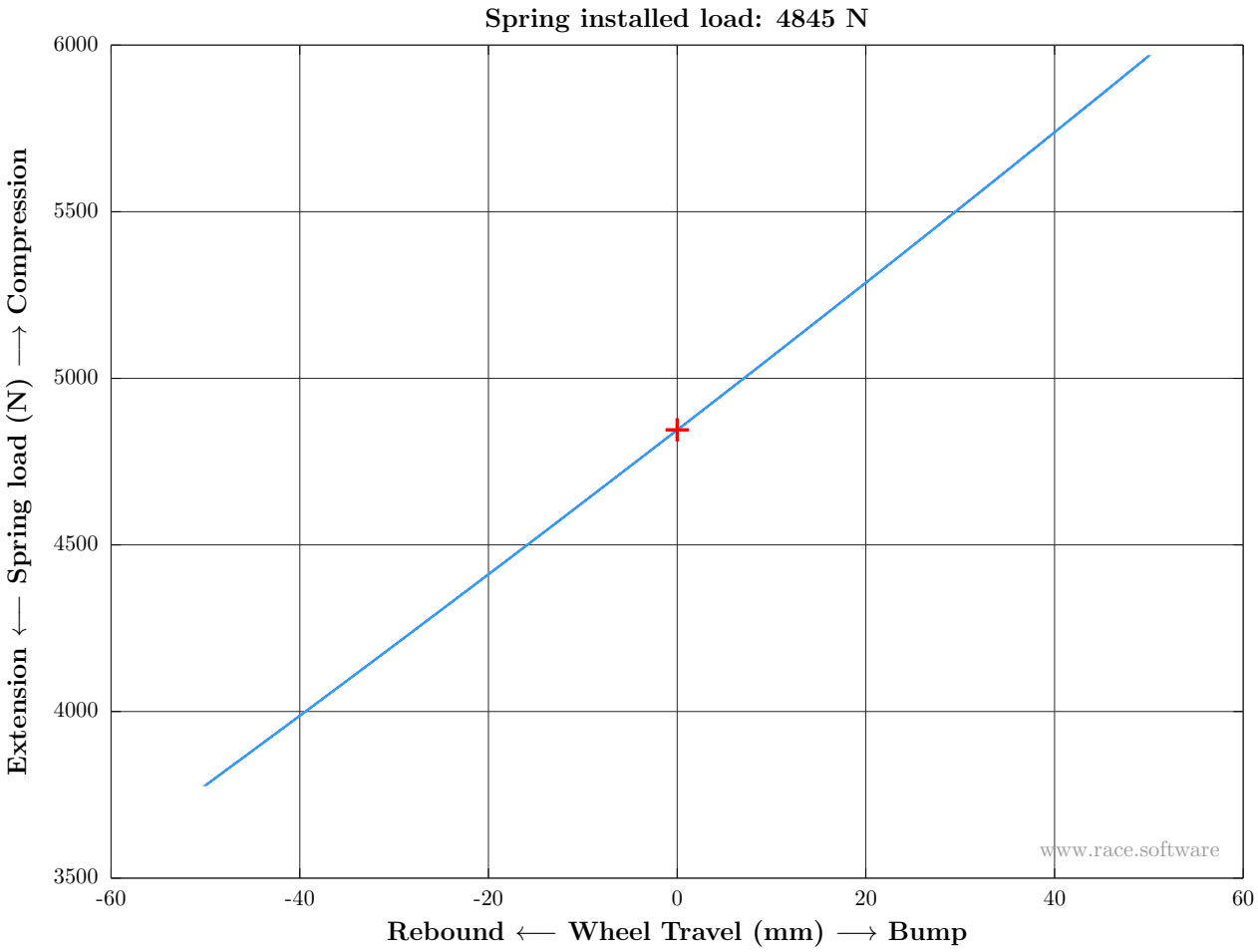

Figure 17: Vertical test: Spring installed load

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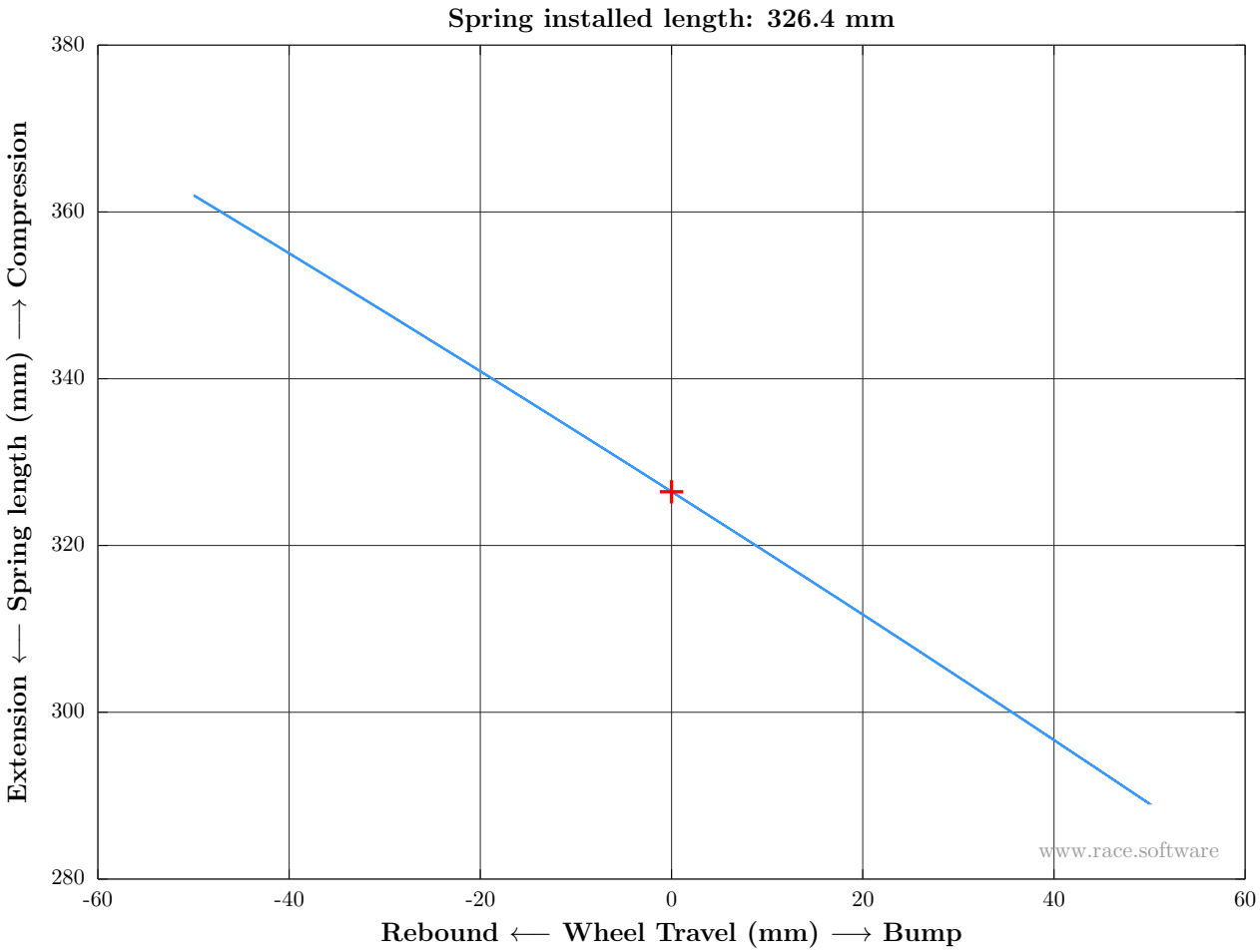

Figure 18: Vertical test: Spring installed length

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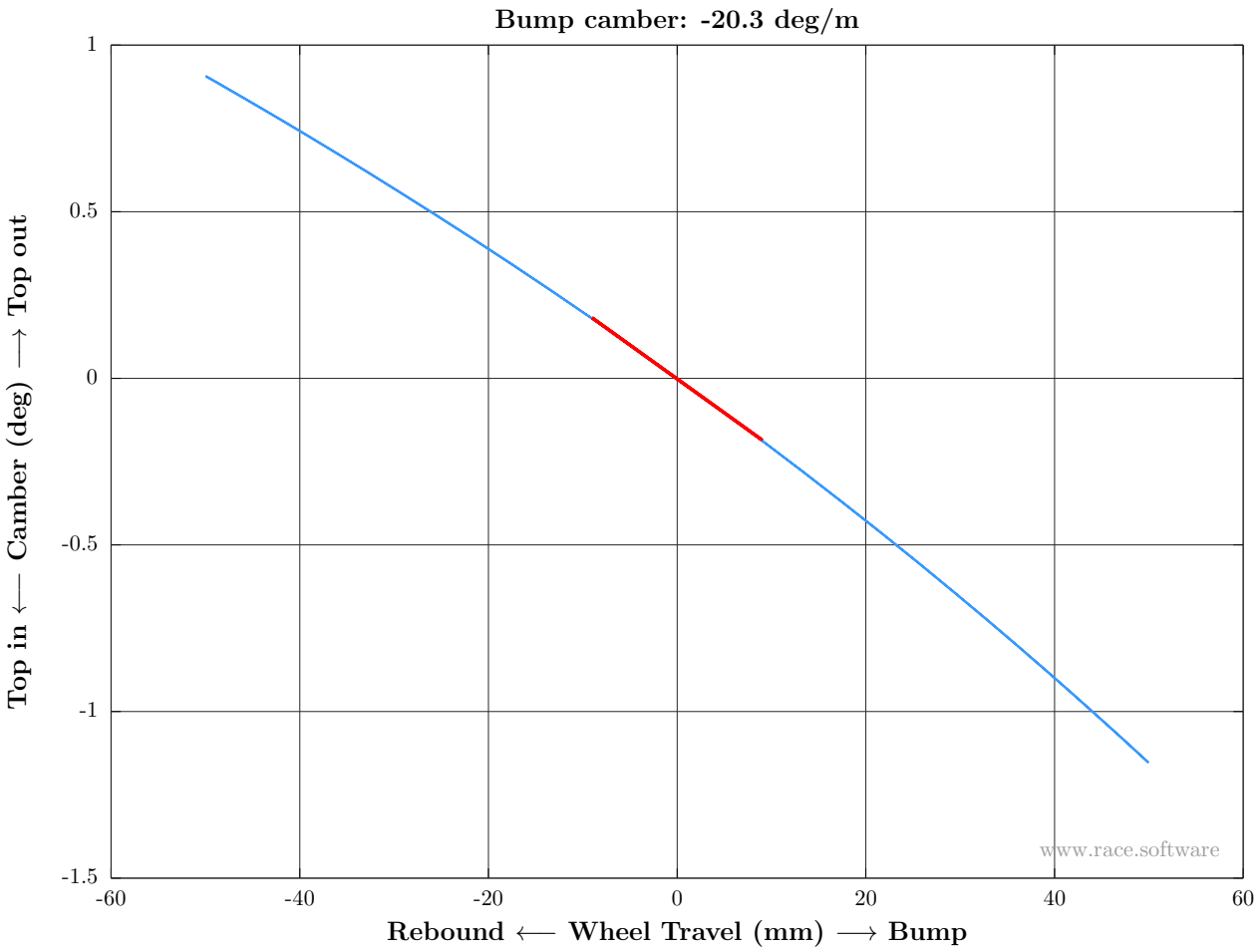

Figure 19: Vertical test: Bump camber

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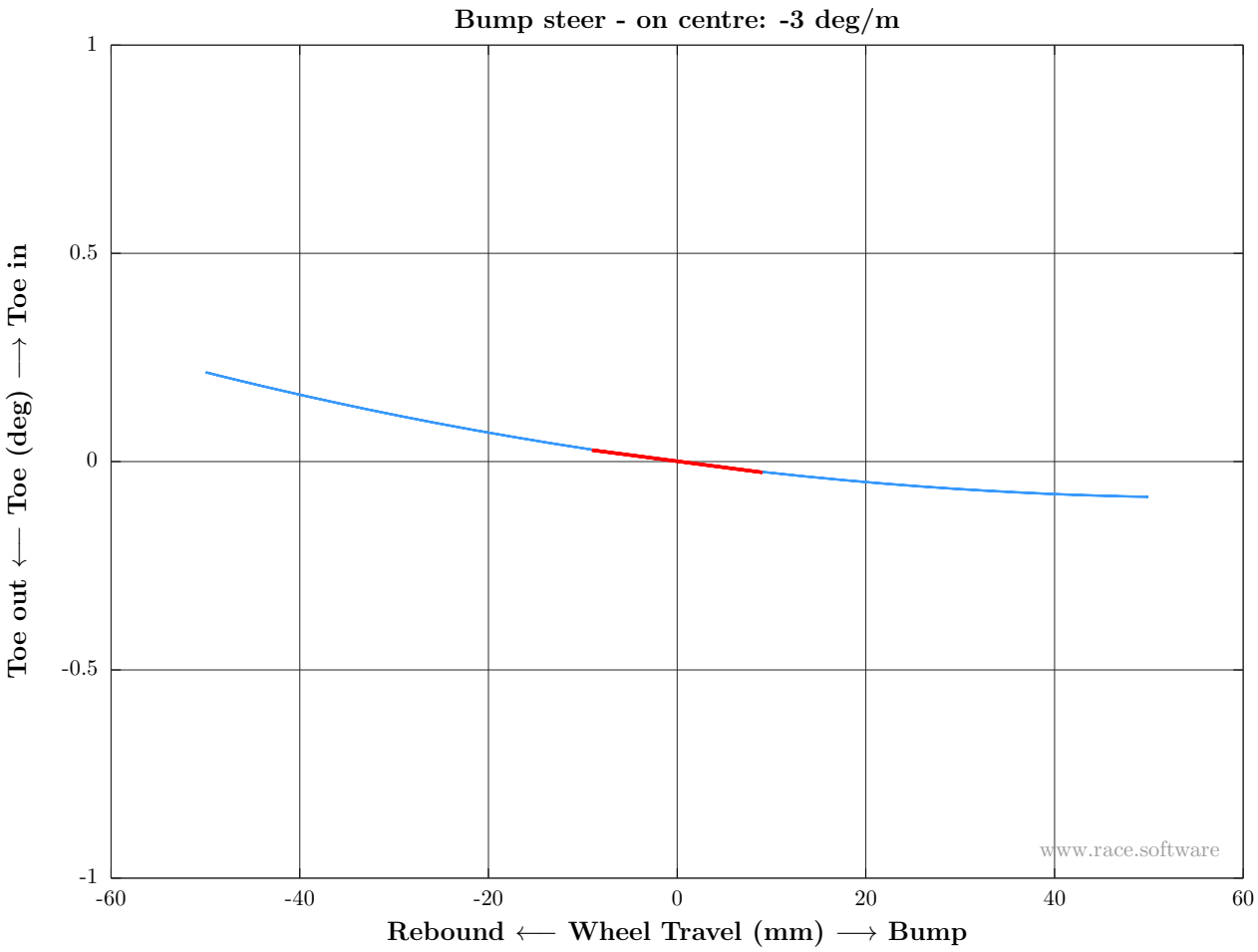

Figure 20: Vertical test: Bump steer - on centre

⟸ **Back to KPI Summary**

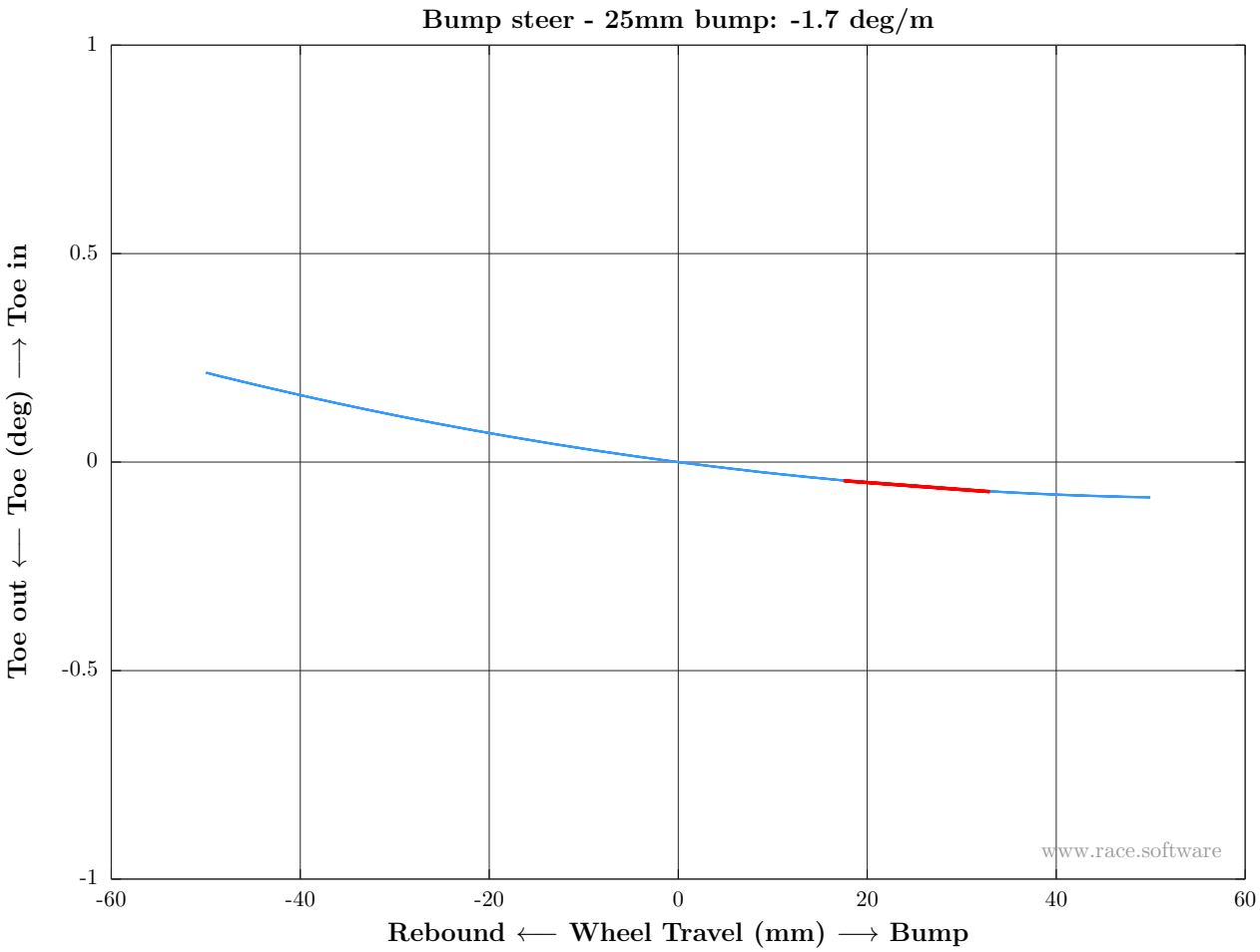

Figure 21: Vertical test: Bump steer - 25mm bump

⟸ **Back to KPI Summary**

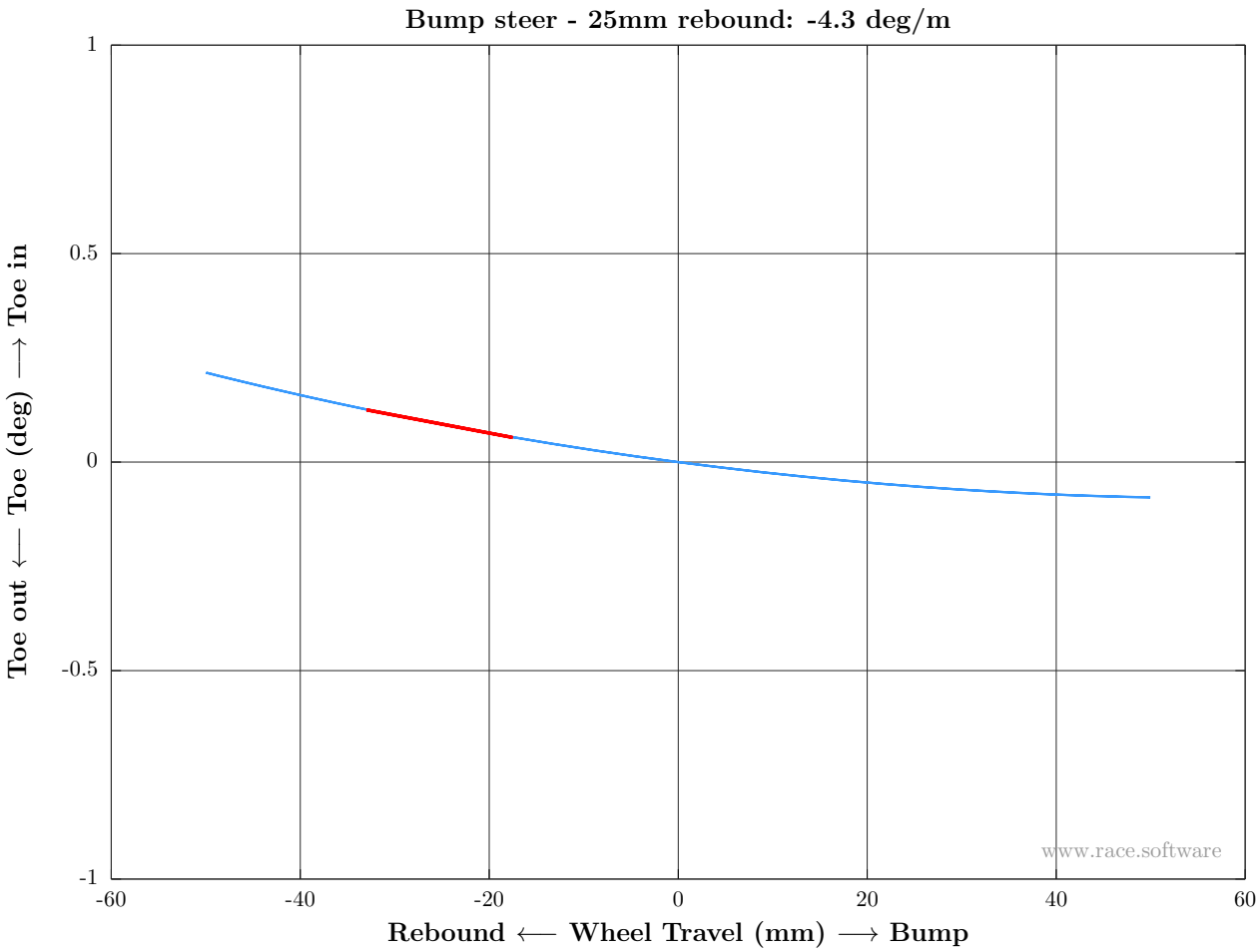

Figure 22: Vertical test: Bump steer - 25mm rebound

⟸ Back to KPI Summary

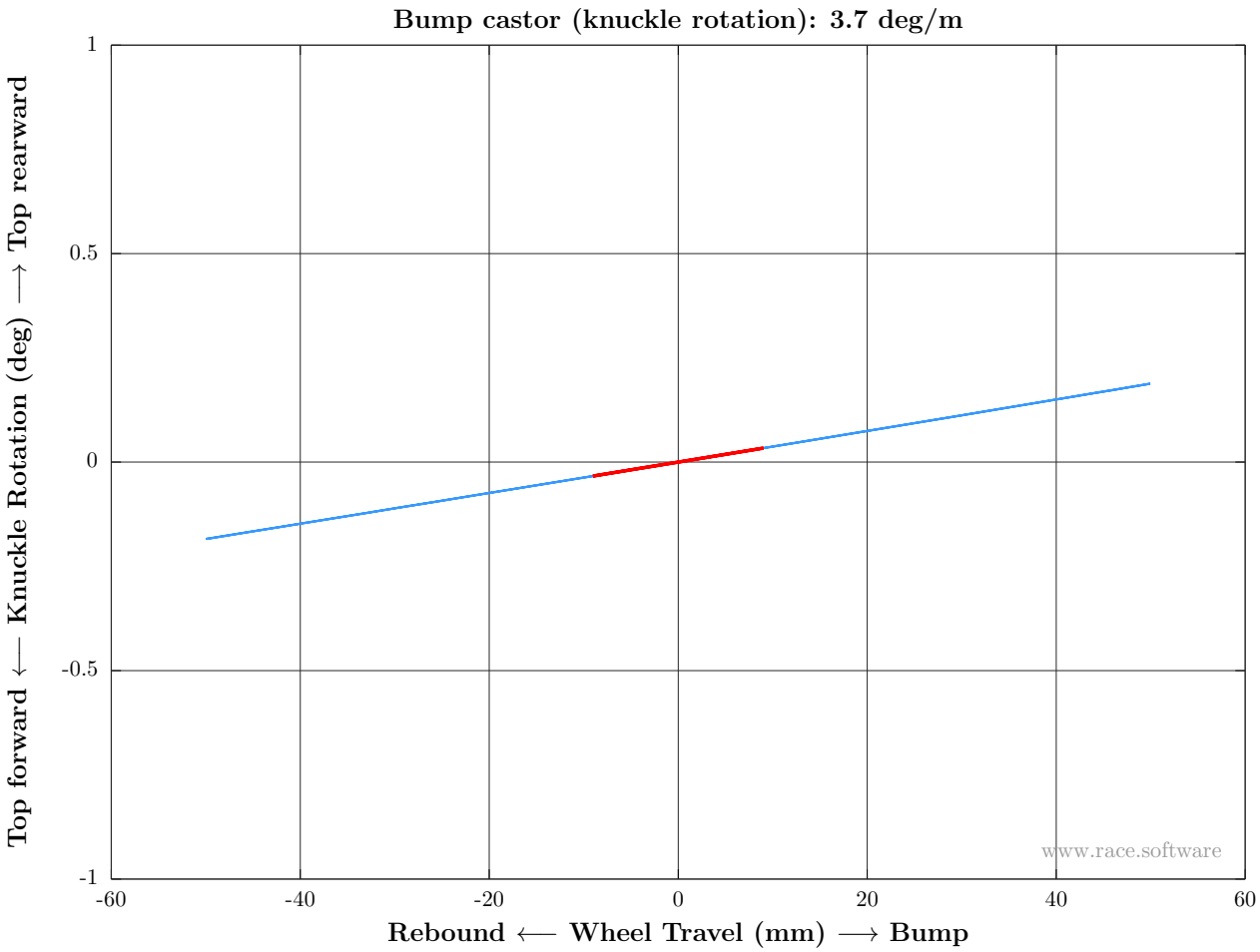

Figure 23: Vertical test: Bump castor (knuckle rotation)

⟸ **Back to KPI Summary**

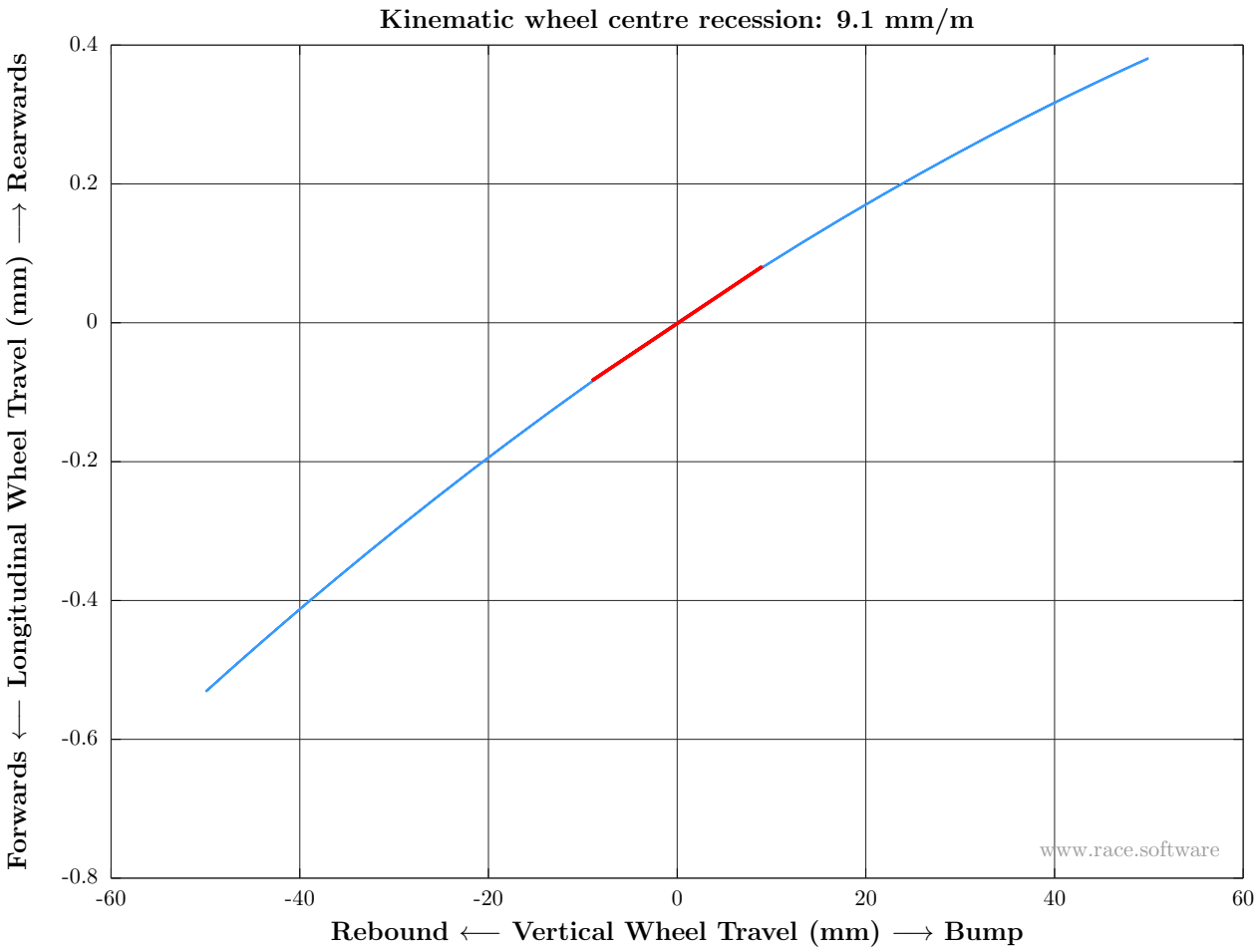

Figure 24: Vertical test: Kinematic wheel centre recession

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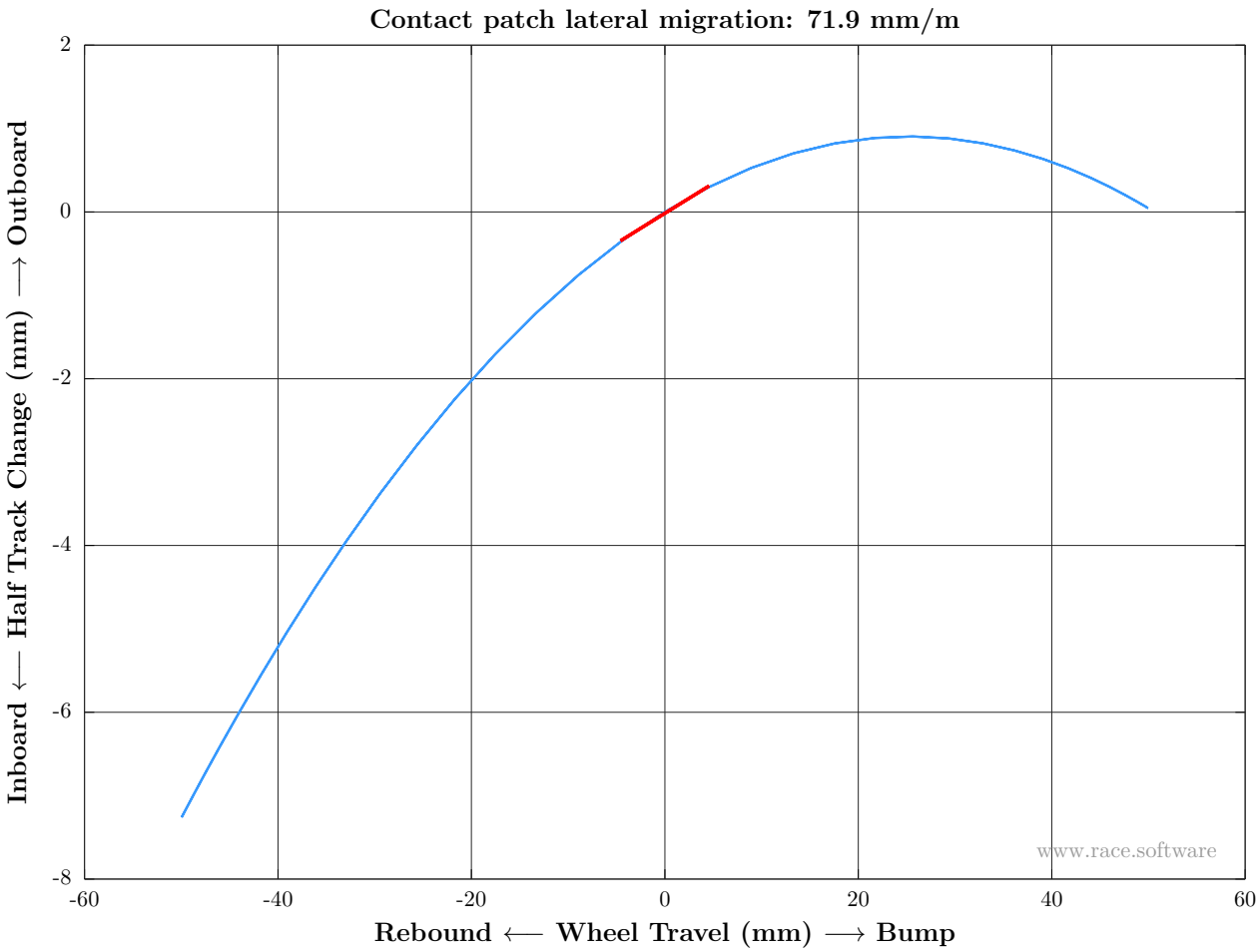

Figure 25: Vertical test: Contact patch lateral migration

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Figure 26: Vertical test: Wheel rate - on centre

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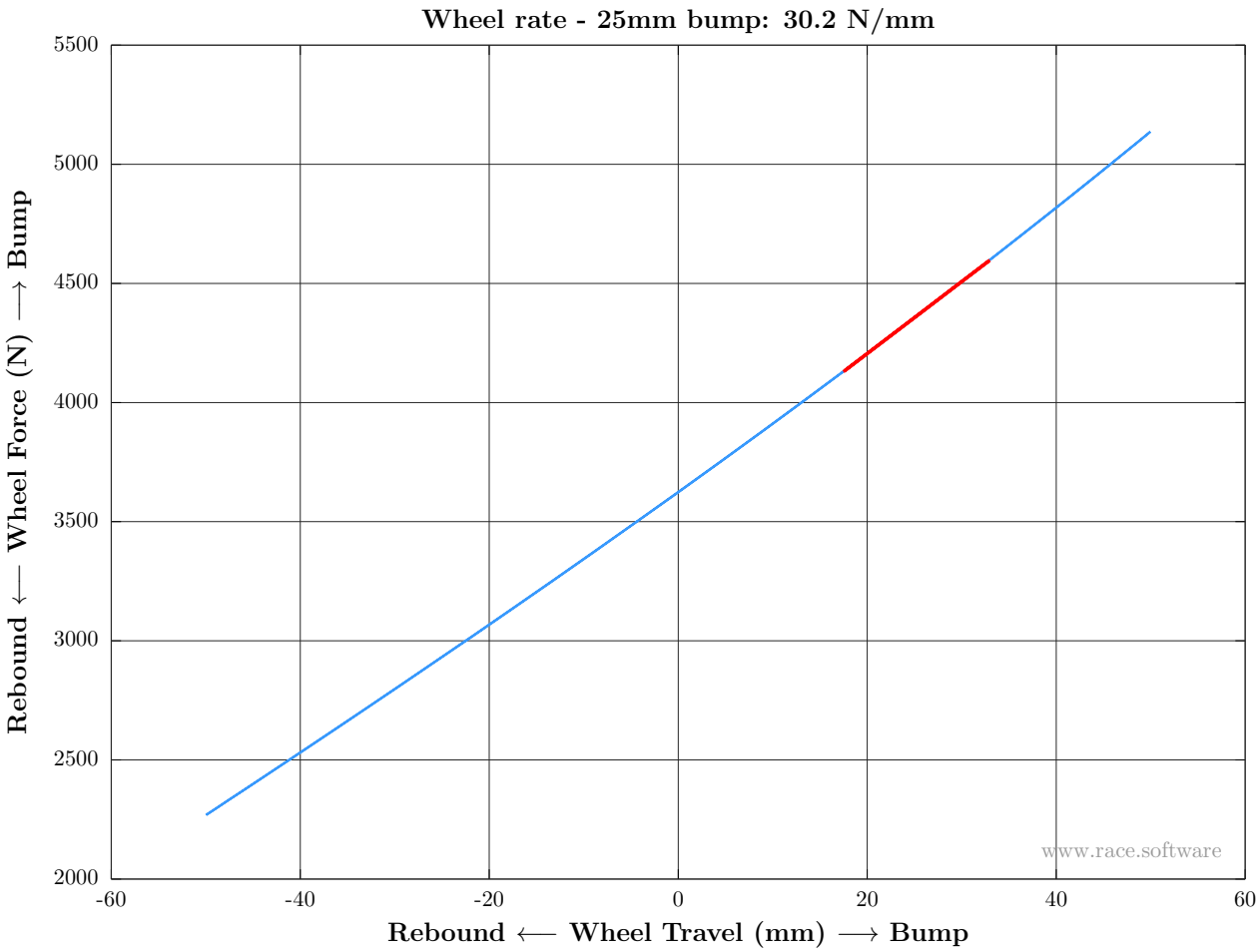

Figure 27: Vertical test: Wheel rate - 25mm bump

⟸ **Back to KPI Summary**

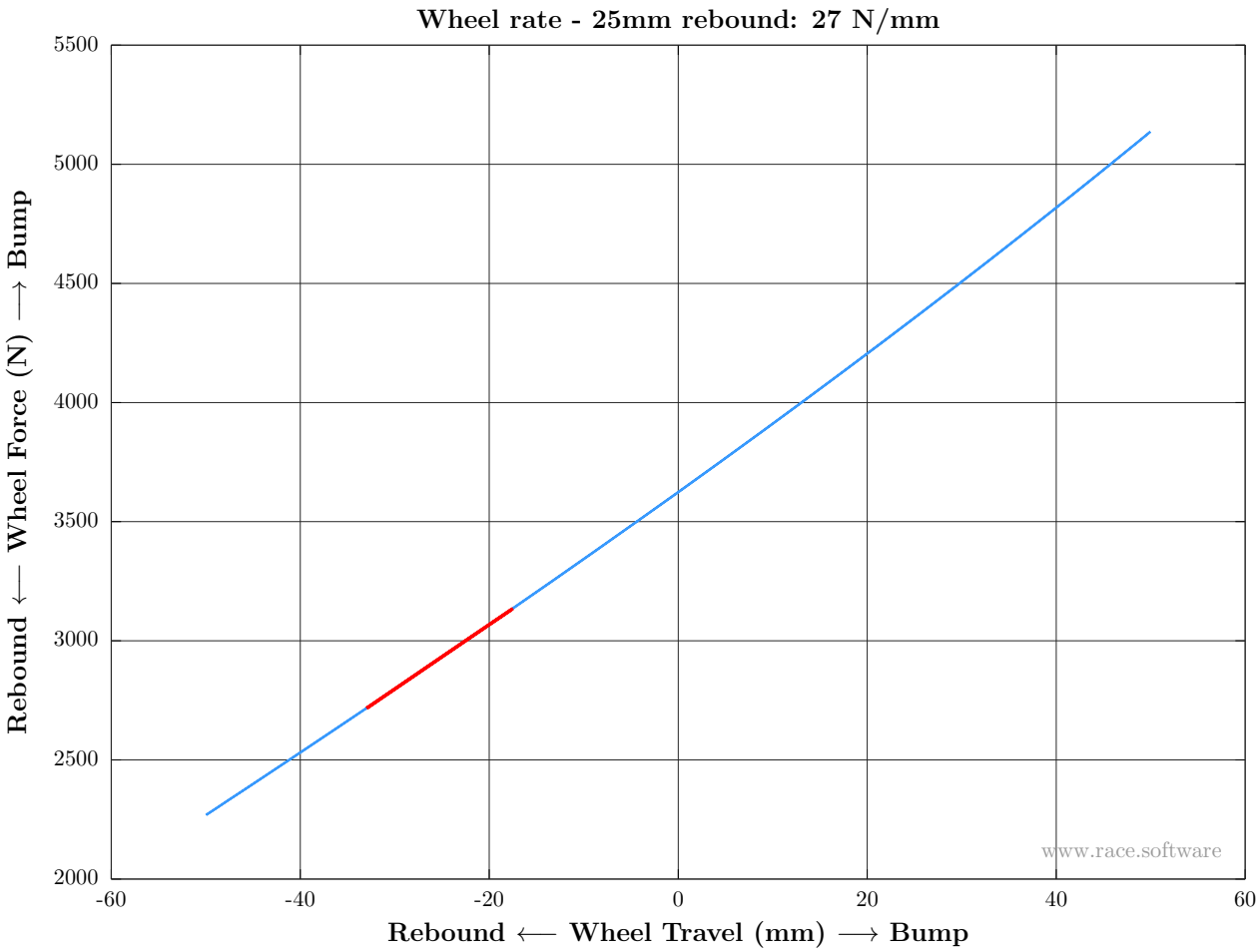

Figure 28: Vertical test: Wheel rate - 25mm rebound

⟸ **Back to KPI Summary**

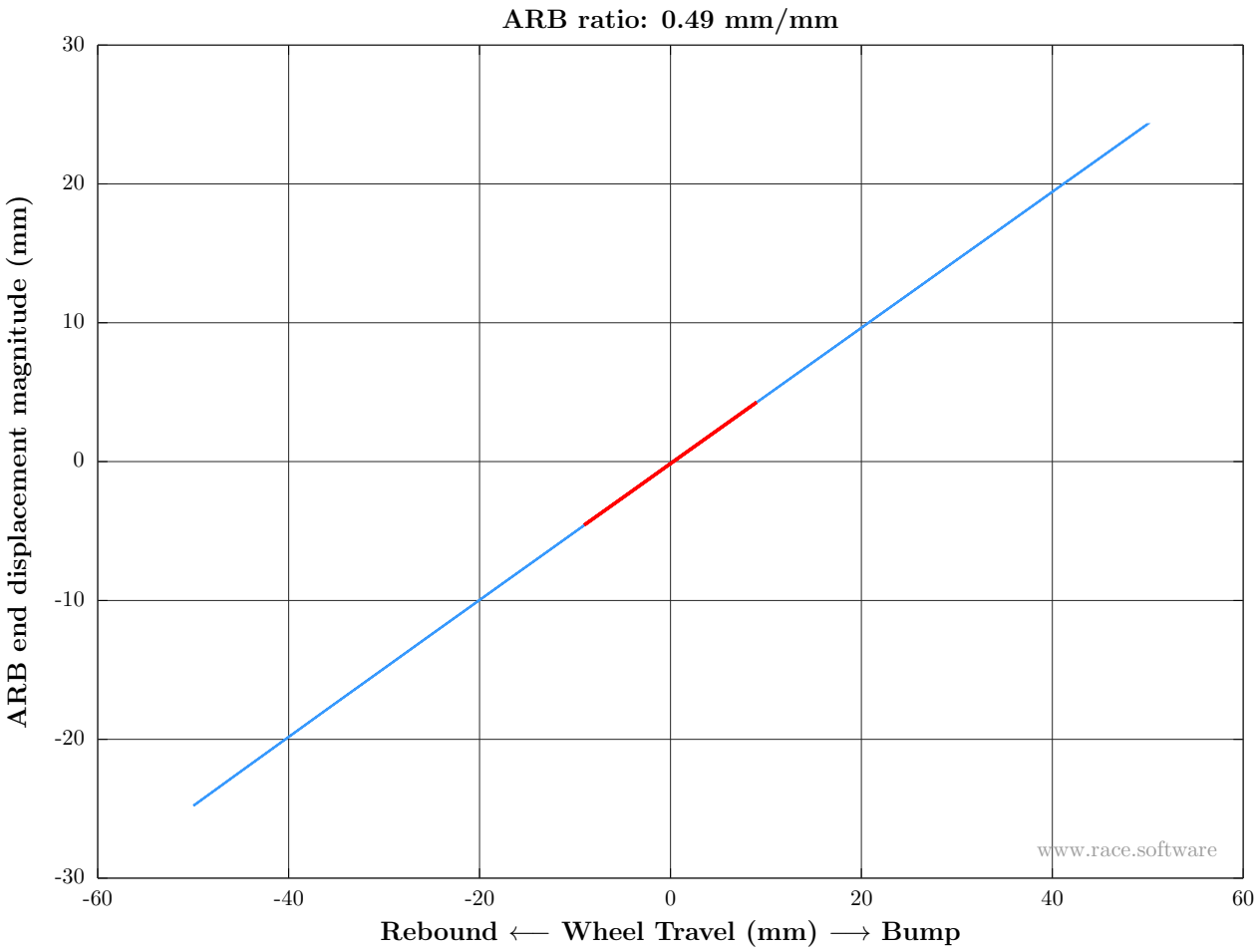

Figure 29: Roll test: ARB ratio

⟸ **Back to KPI Summary**

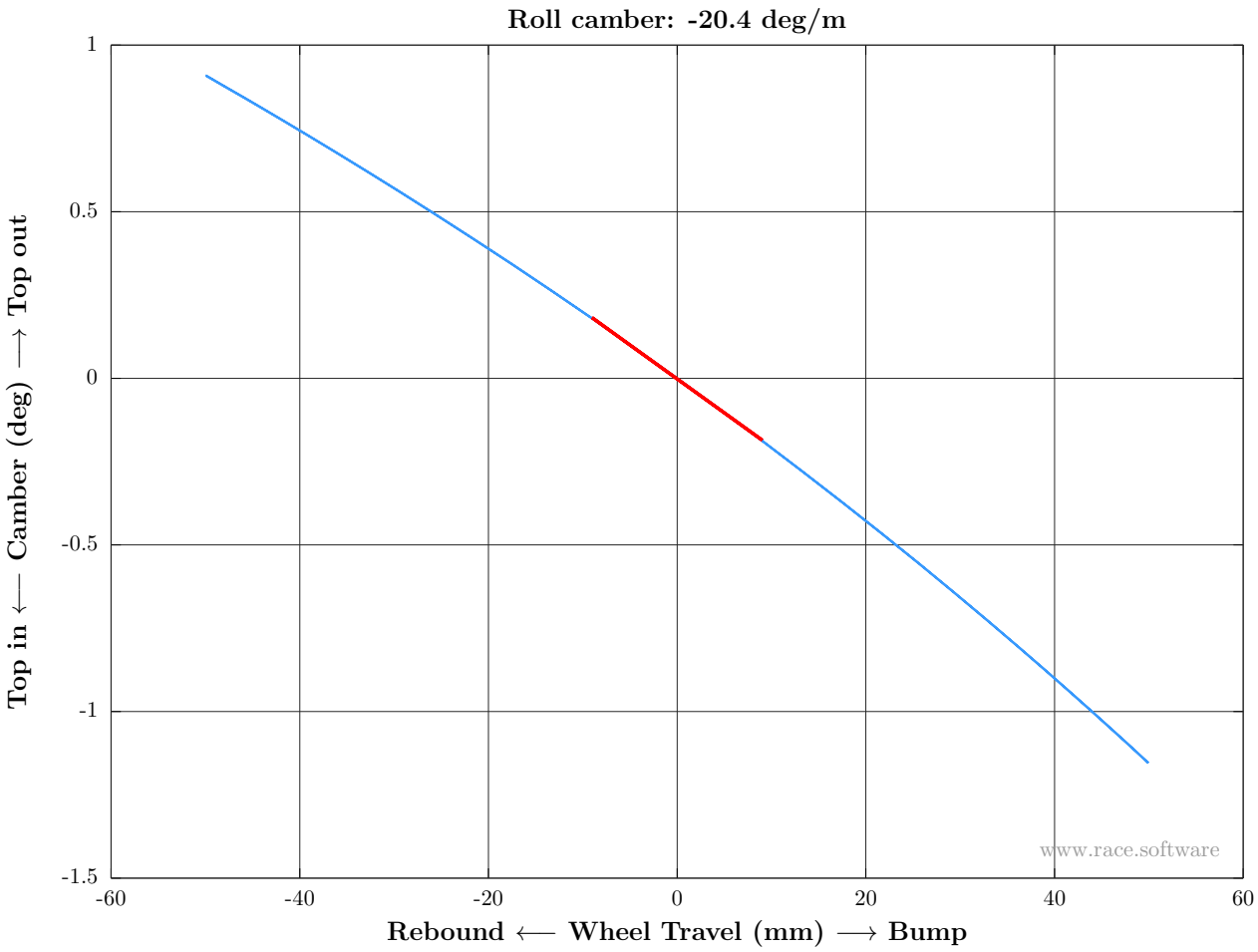

Figure 30: Roll test: Roll camber

⟸ **Back to KPI Summary**

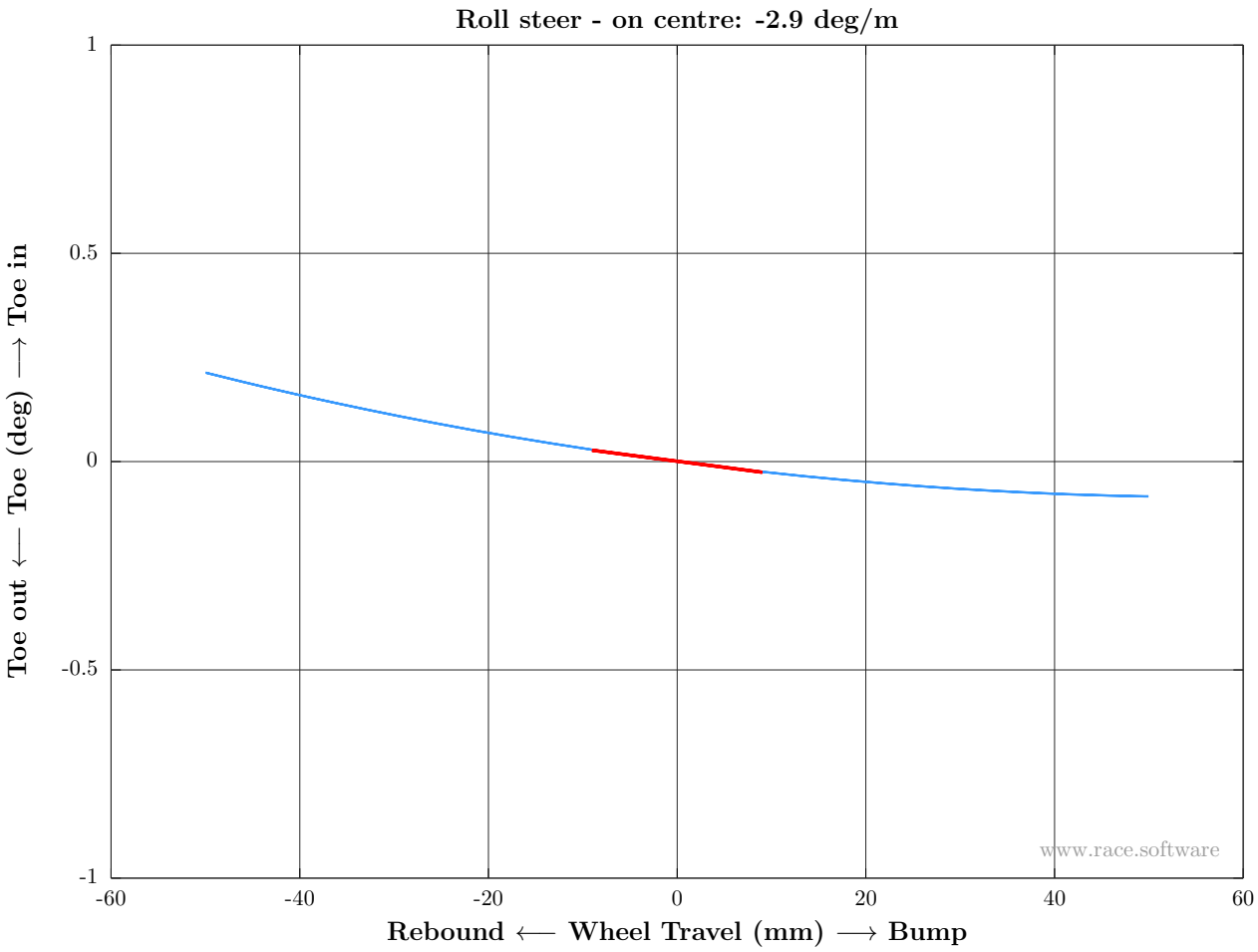

Figure 31: Roll test: Roll steer - on centre

⟸ **Back to KPI Summary**

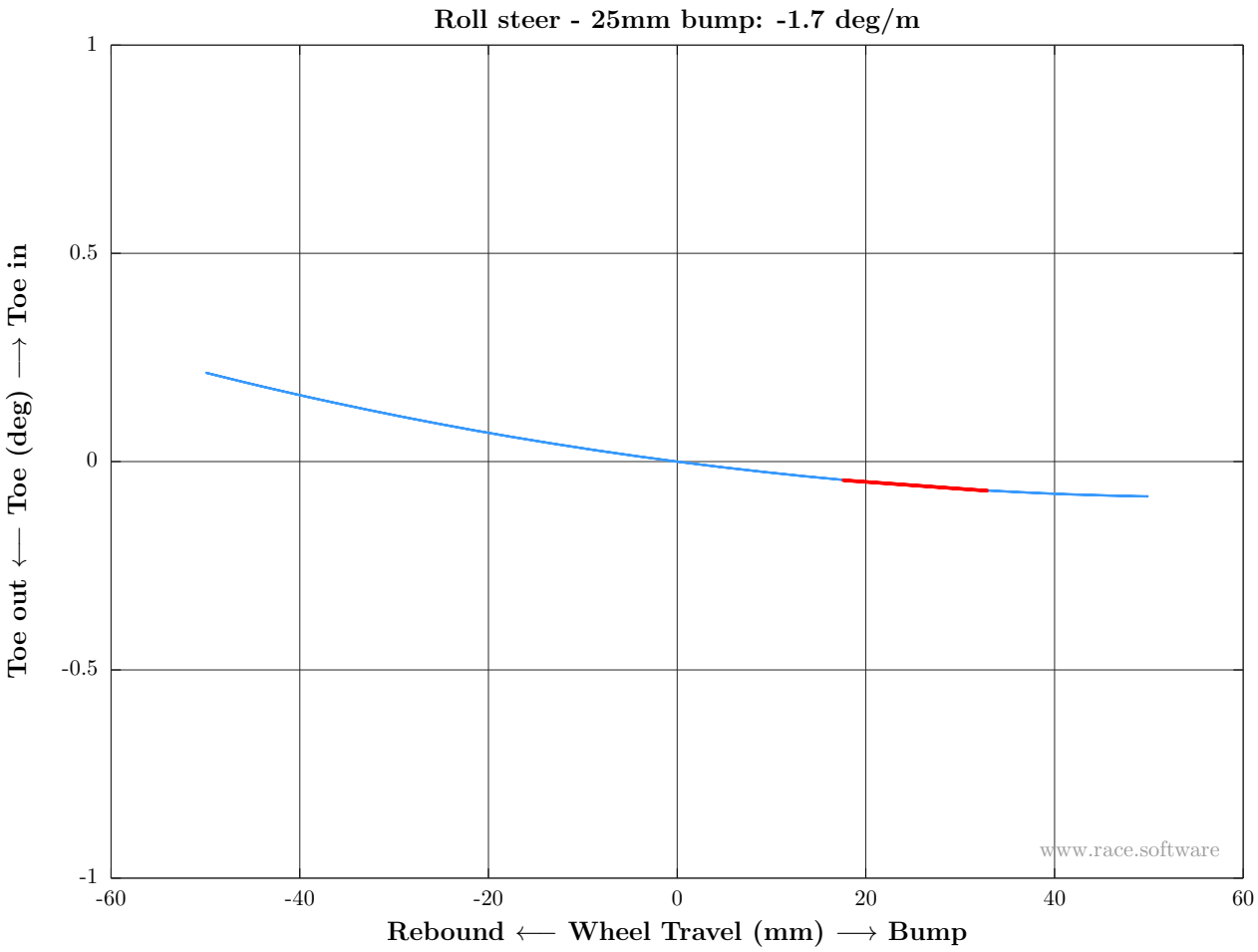

Figure 32: Roll test: Roll steer - 25mm bump

⟸ **Back to KPI Summary**

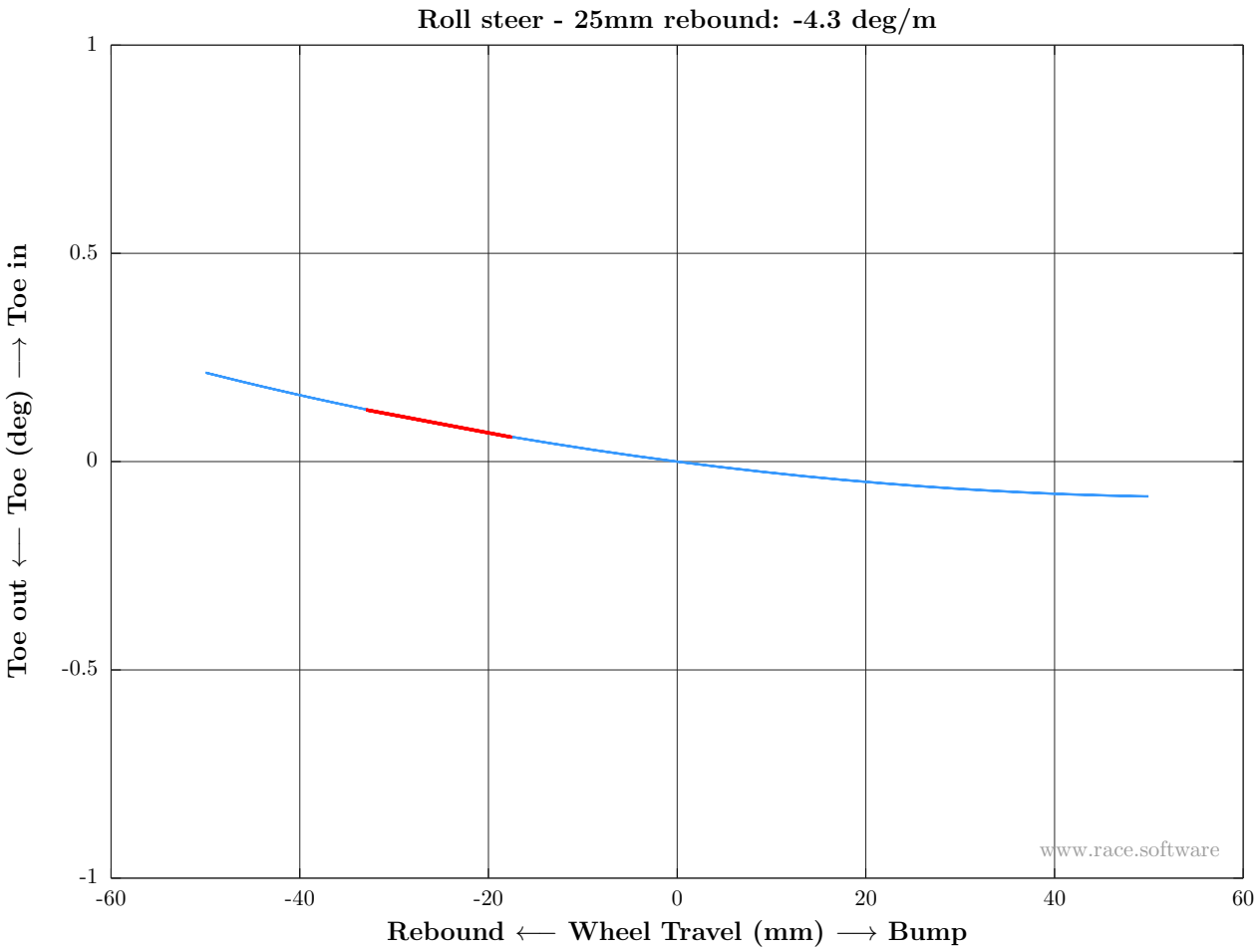

Figure 33: Roll test: Roll steer - 25mm rebound

⟸ Back to KPI Summary

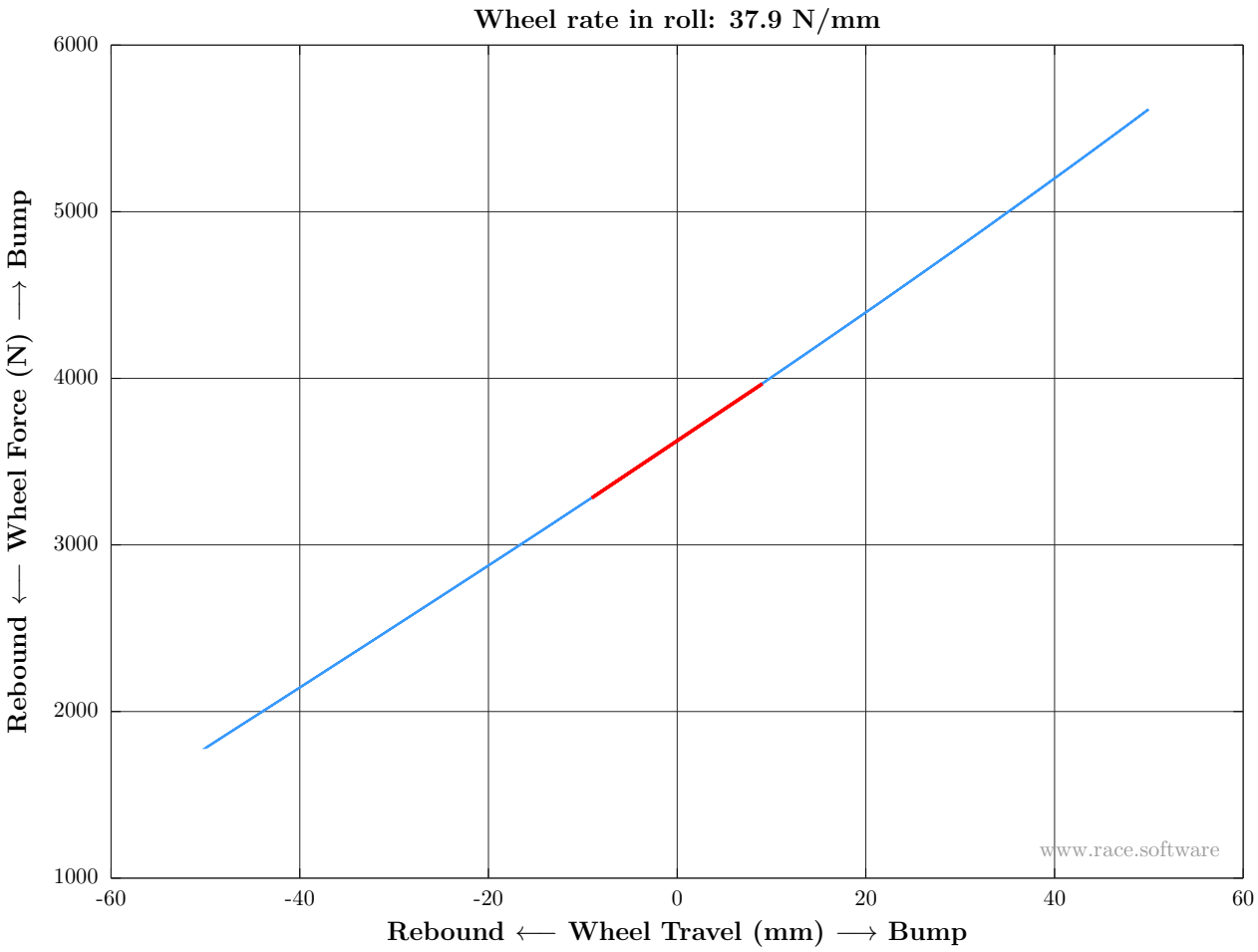

Figure 34: Roll test: Wheel rate in roll

⟸ **Back to KPI Summary**

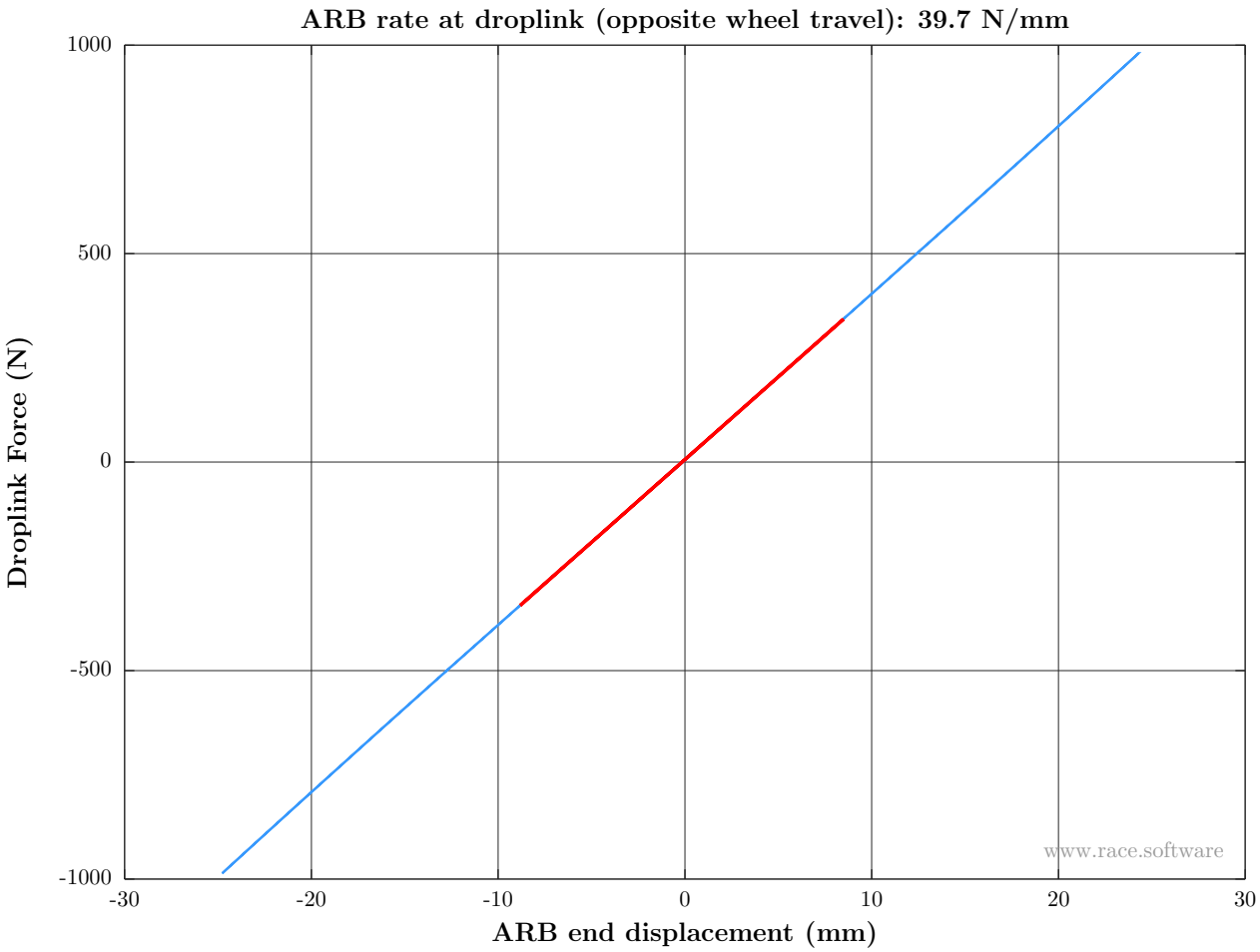

Figure 35: Roll test: ARB rate at droplink (opposite wheel travel)

⟸ **Back to KPI Summary**

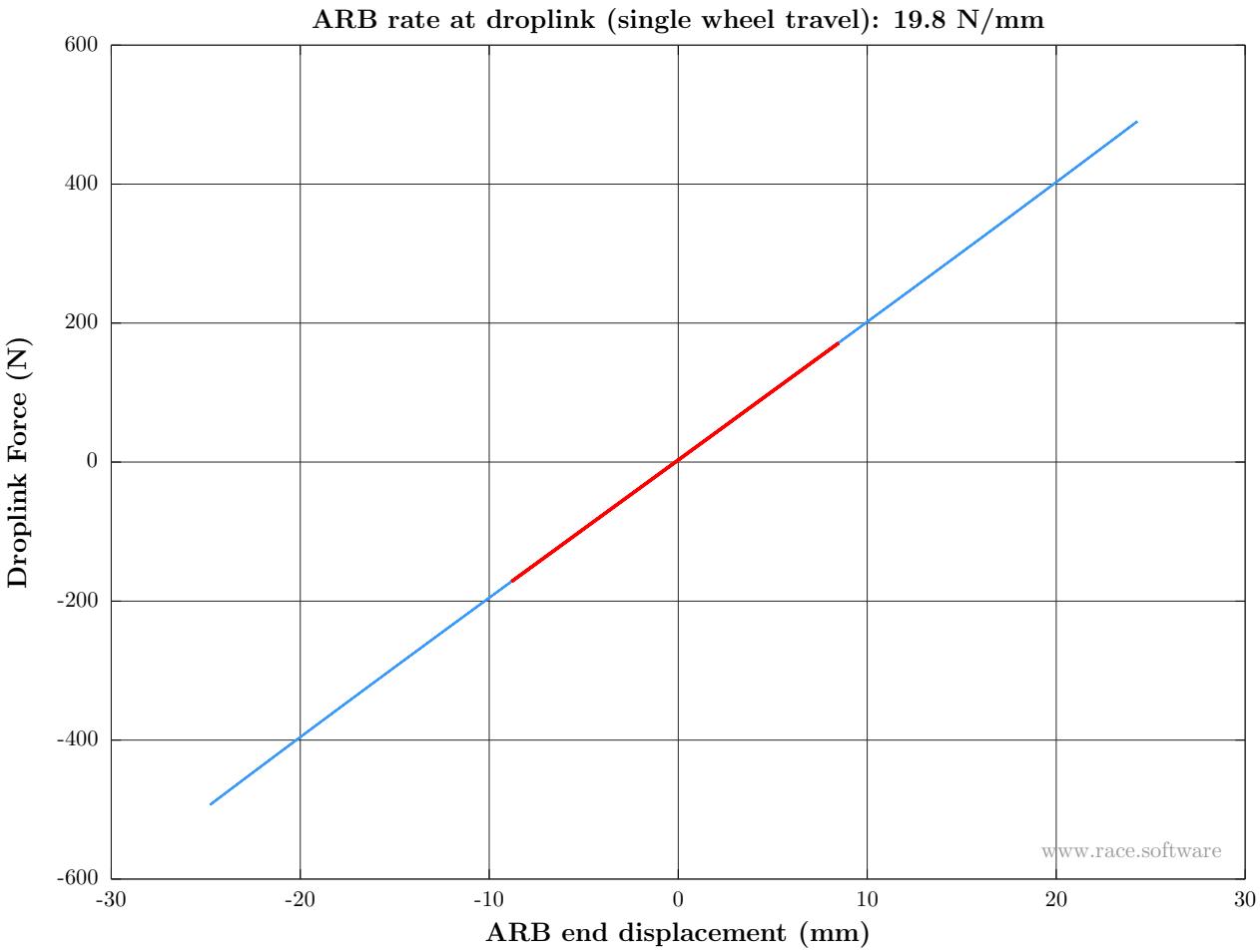

Figure 36: Roll test: ARB rate at droplink (single wheel travel)

⟸ **Back to KPI Summary**

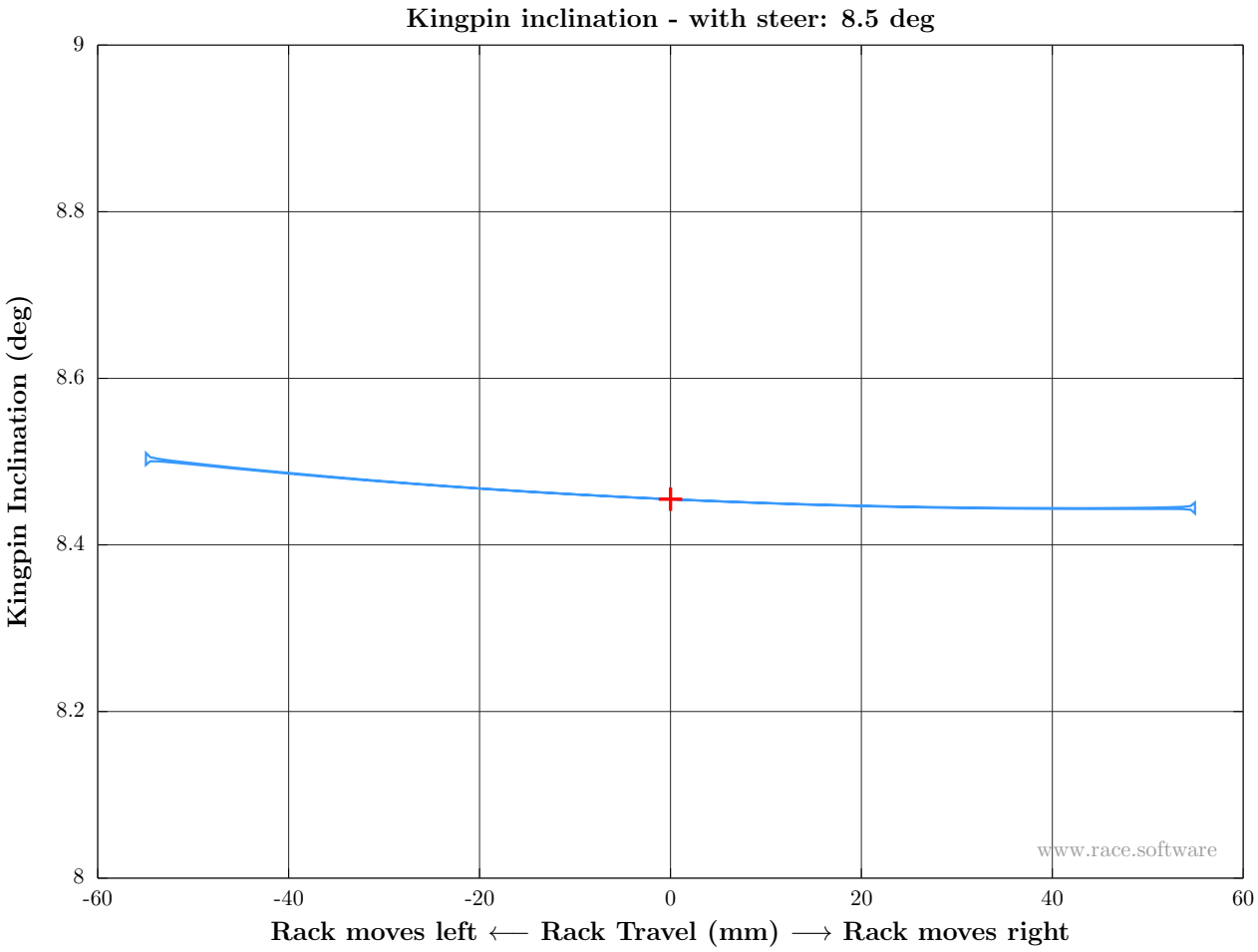

Figure 37: Steering test: Kingpin inclination - with steer

⟸ **Back to KPI Summary**

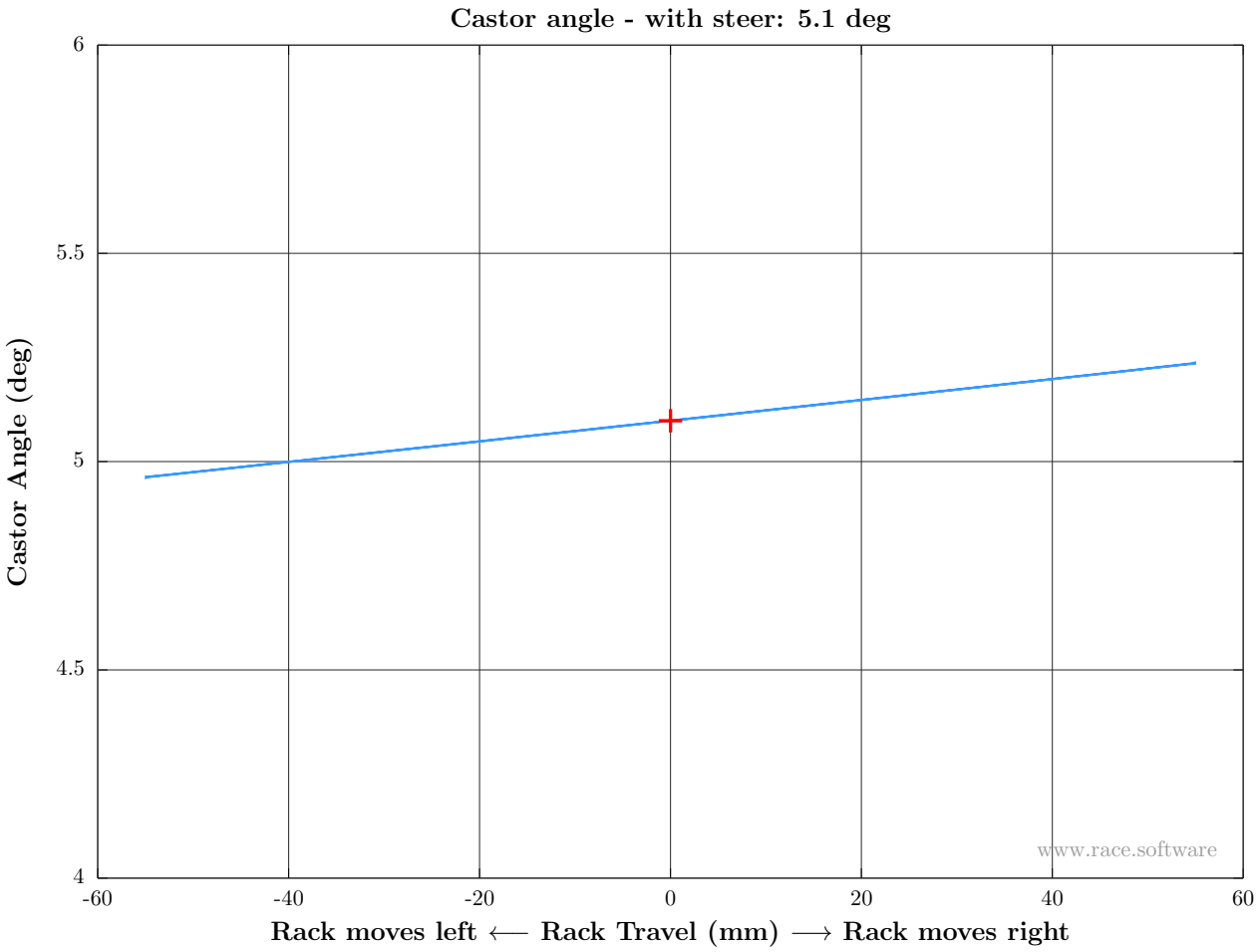

Figure 38: Steering test: Castor angle - with steer

⟸ **Back to KPI Summary**

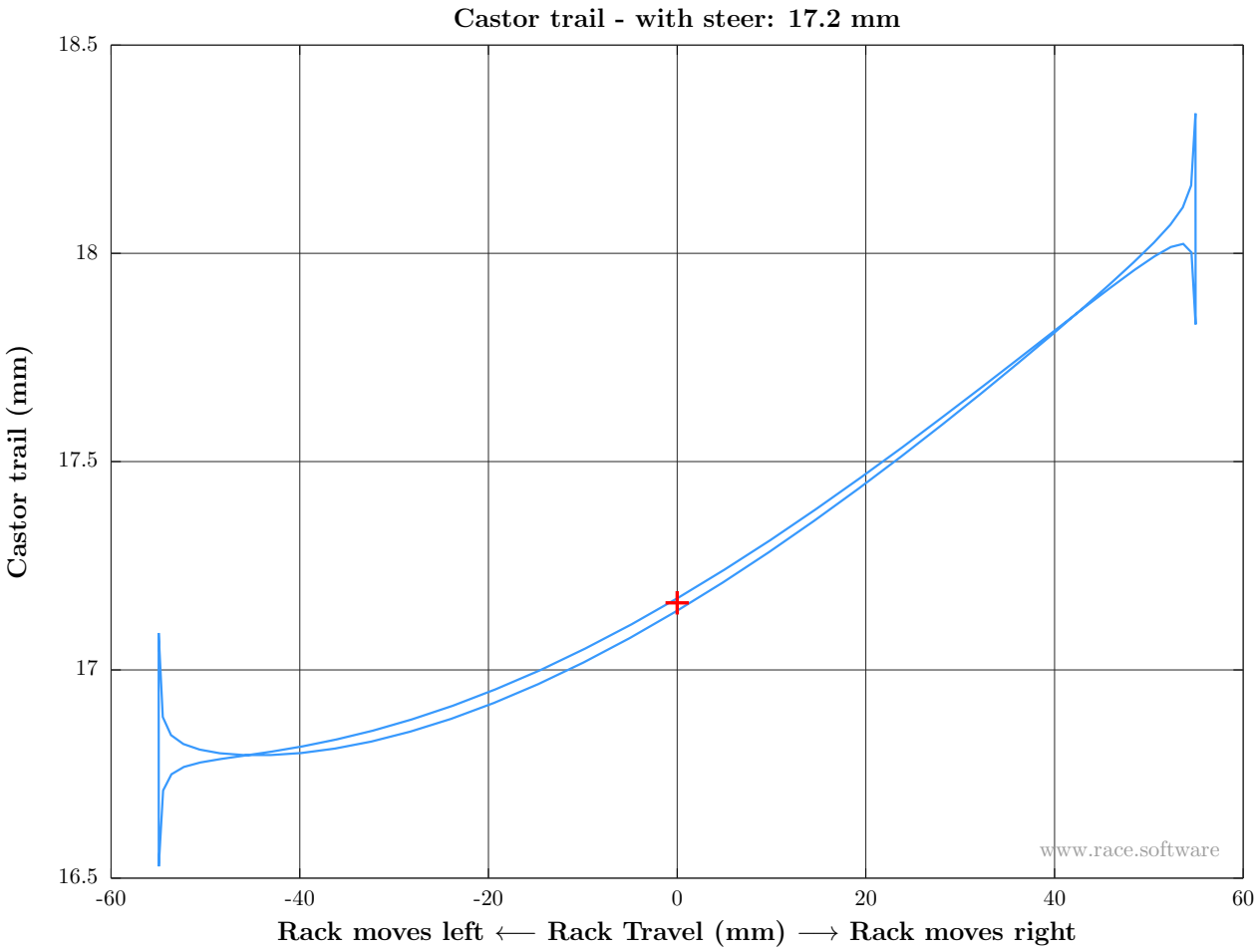

Figure 39: Steering test: Castor trail - with steer

⟸ **Back to KPI Summary**

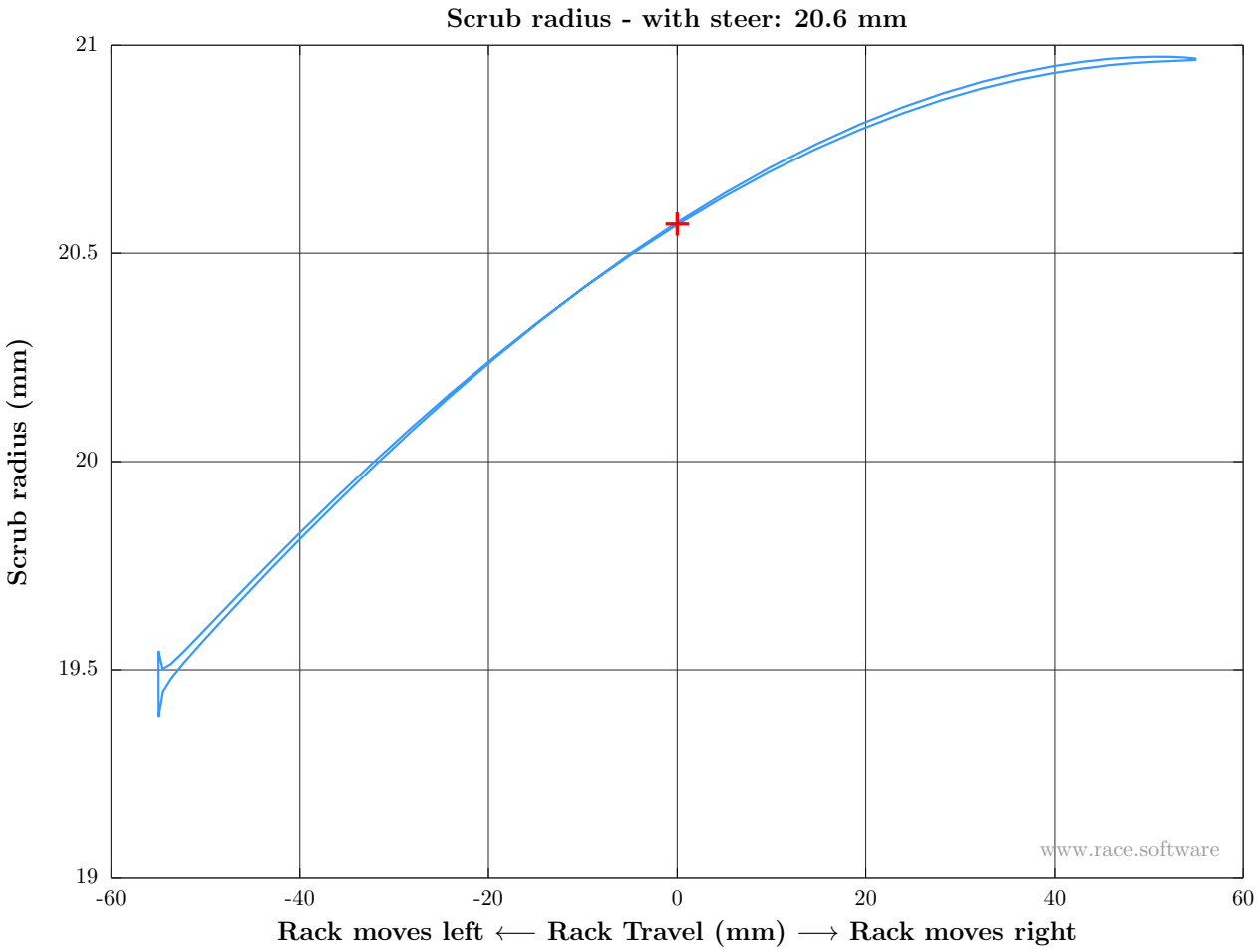

Figure 40: Steering test: Scrub radius - with steer

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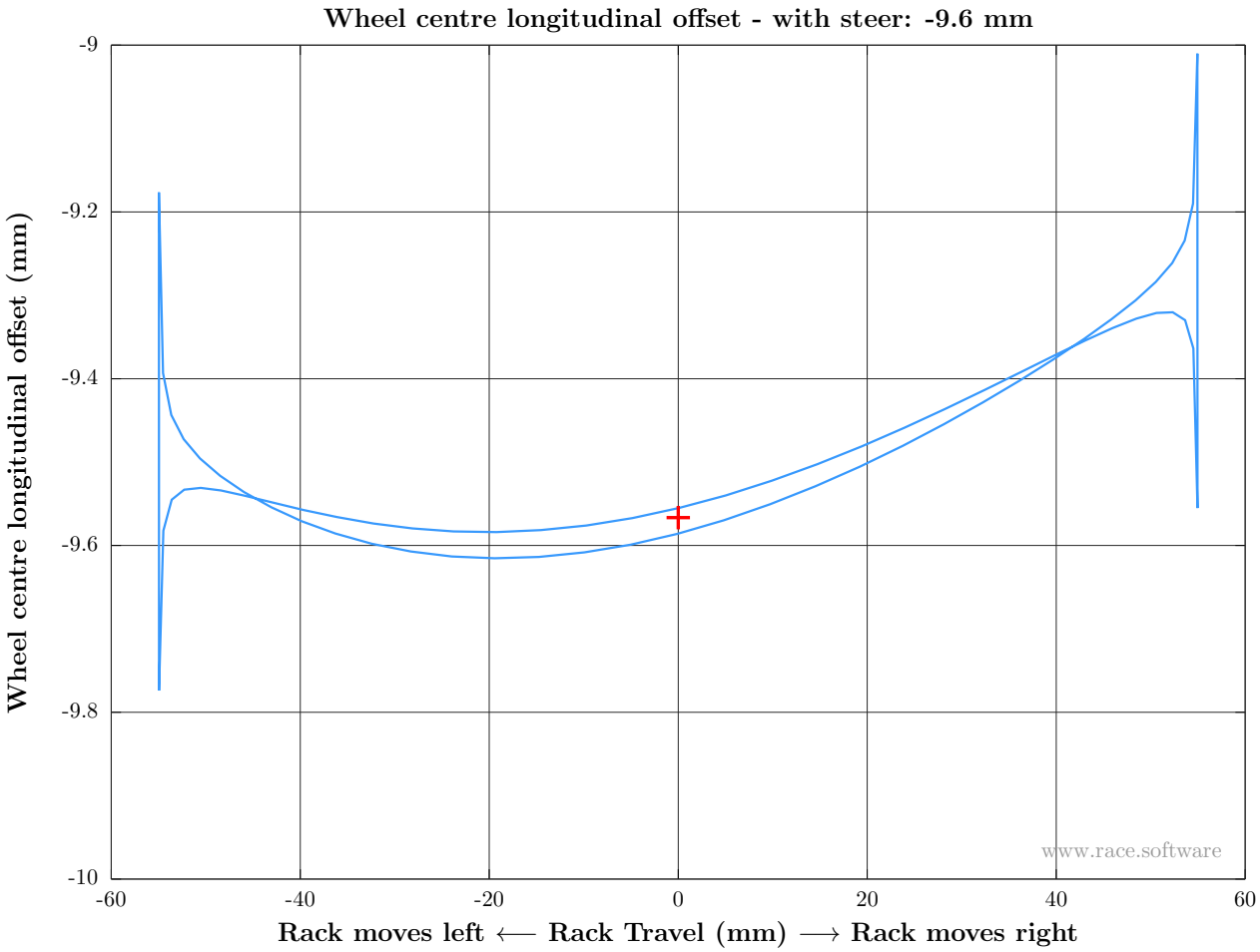

Figure 41: Steering test: Wheel centre longitudinal offset - with steer

⟸ **Back to KPI Summary**

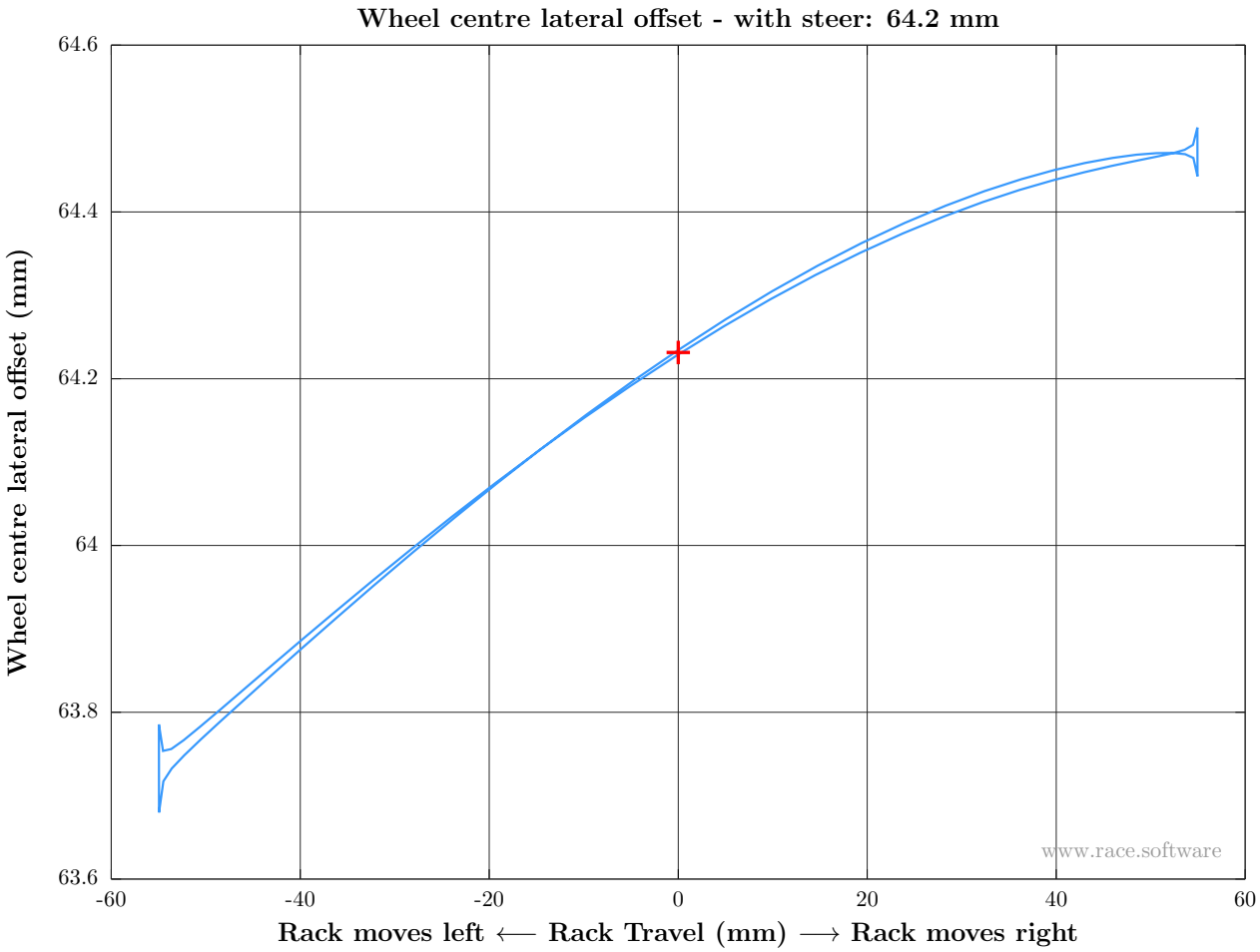

Figure 42: Steering test: Wheel centre lateral offset - with steer

⟸ **Back to KPI Summary**

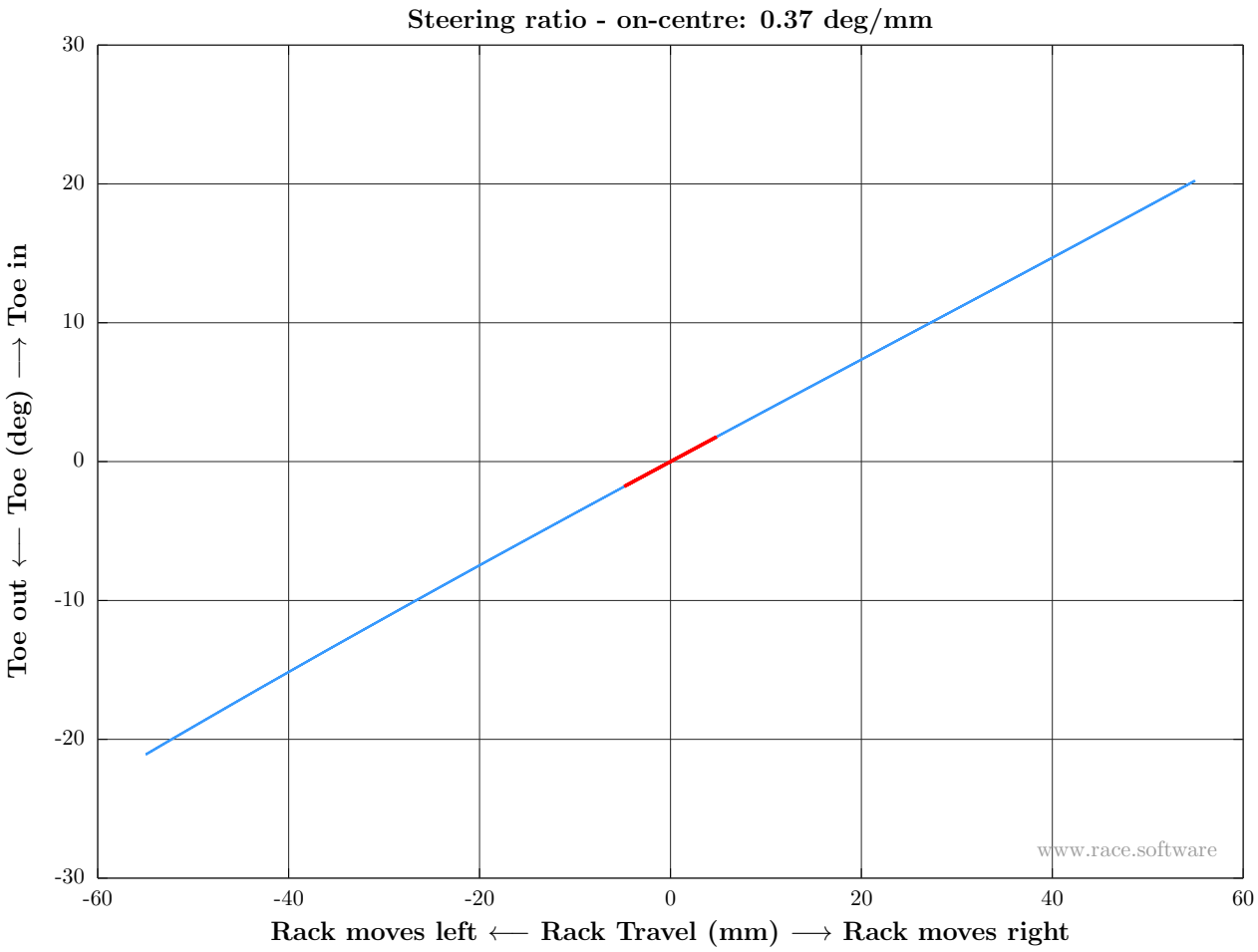

Figure 43: Steering test: Steering ratio - on-centre

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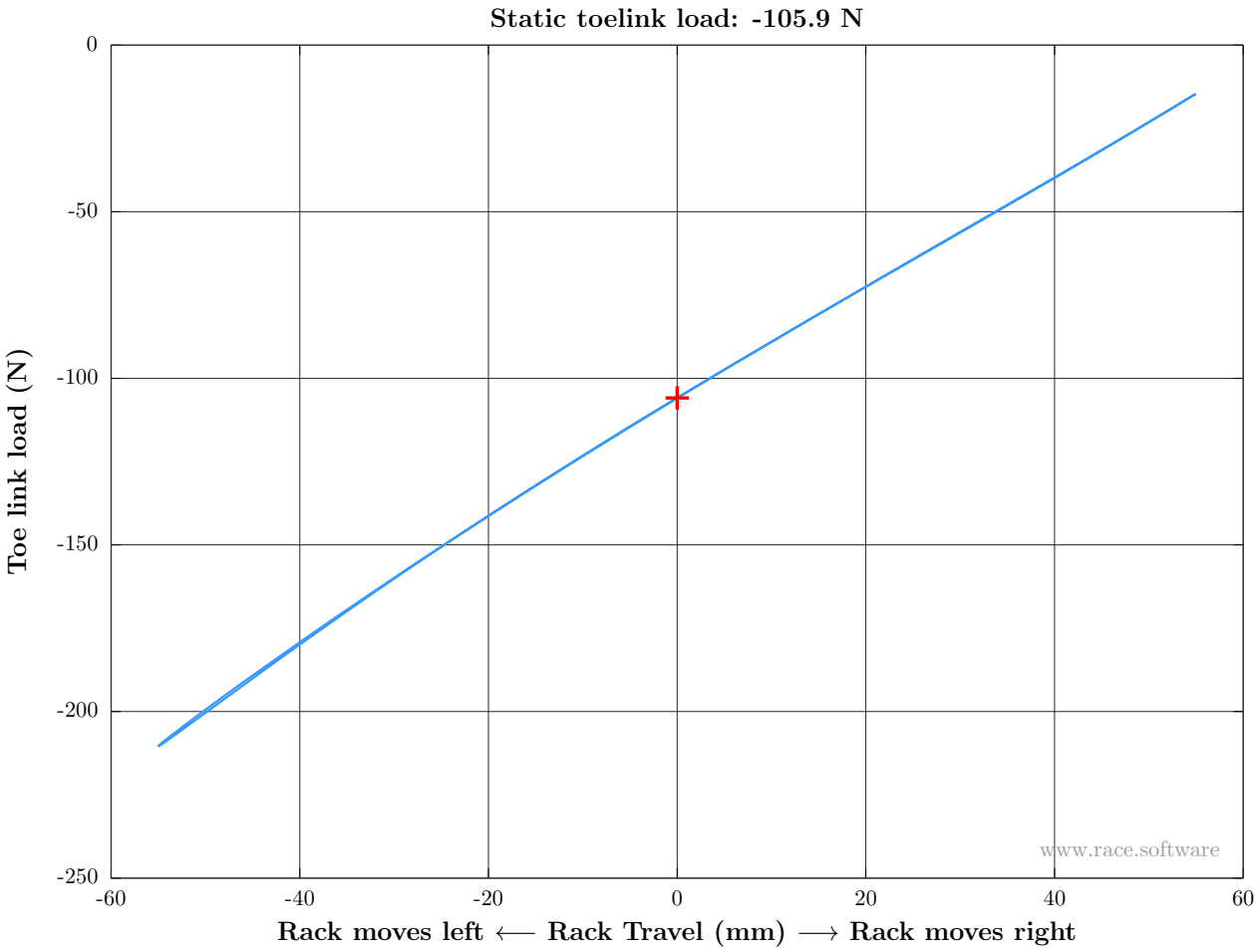

Figure 44: Steering test: Static toelink load

⟸ **Back to KPI Summary**

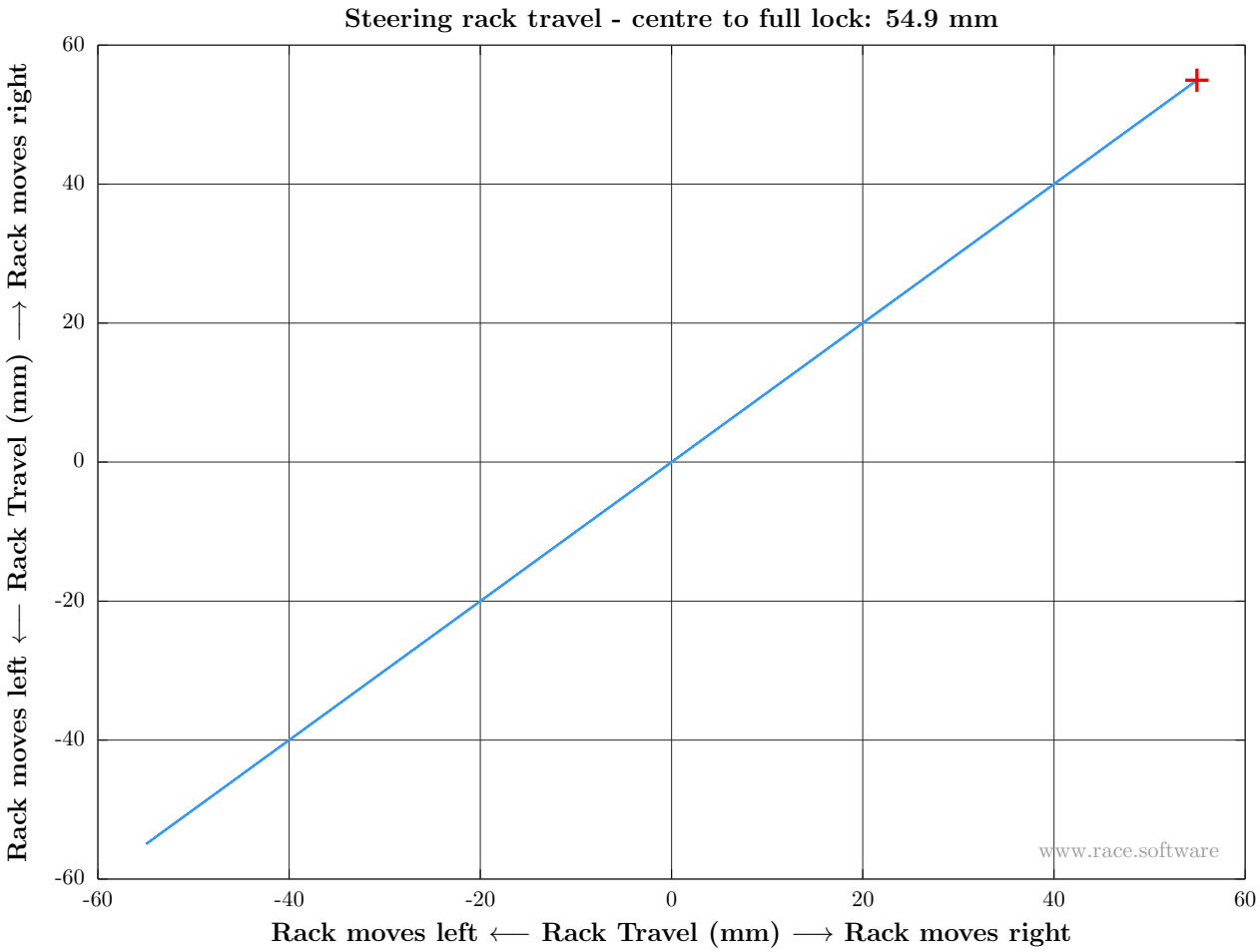

Figure 45: Steering test: Steering rack travel - centre to full lock

⟸ Back to KPI Summary

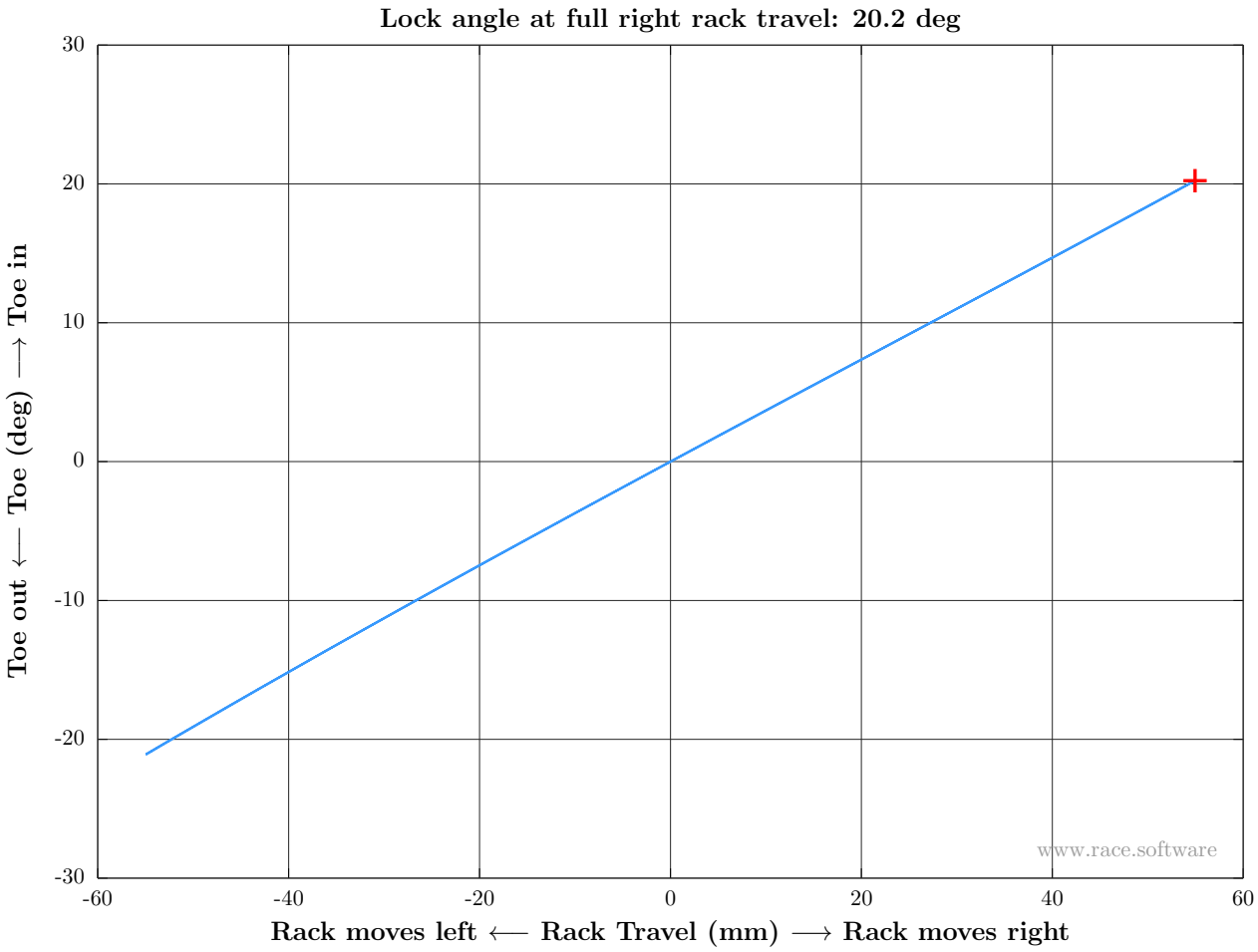

Figure 46: Steering test: Lock angle at full right rack travel

⟸ **Back to KPI Summary**

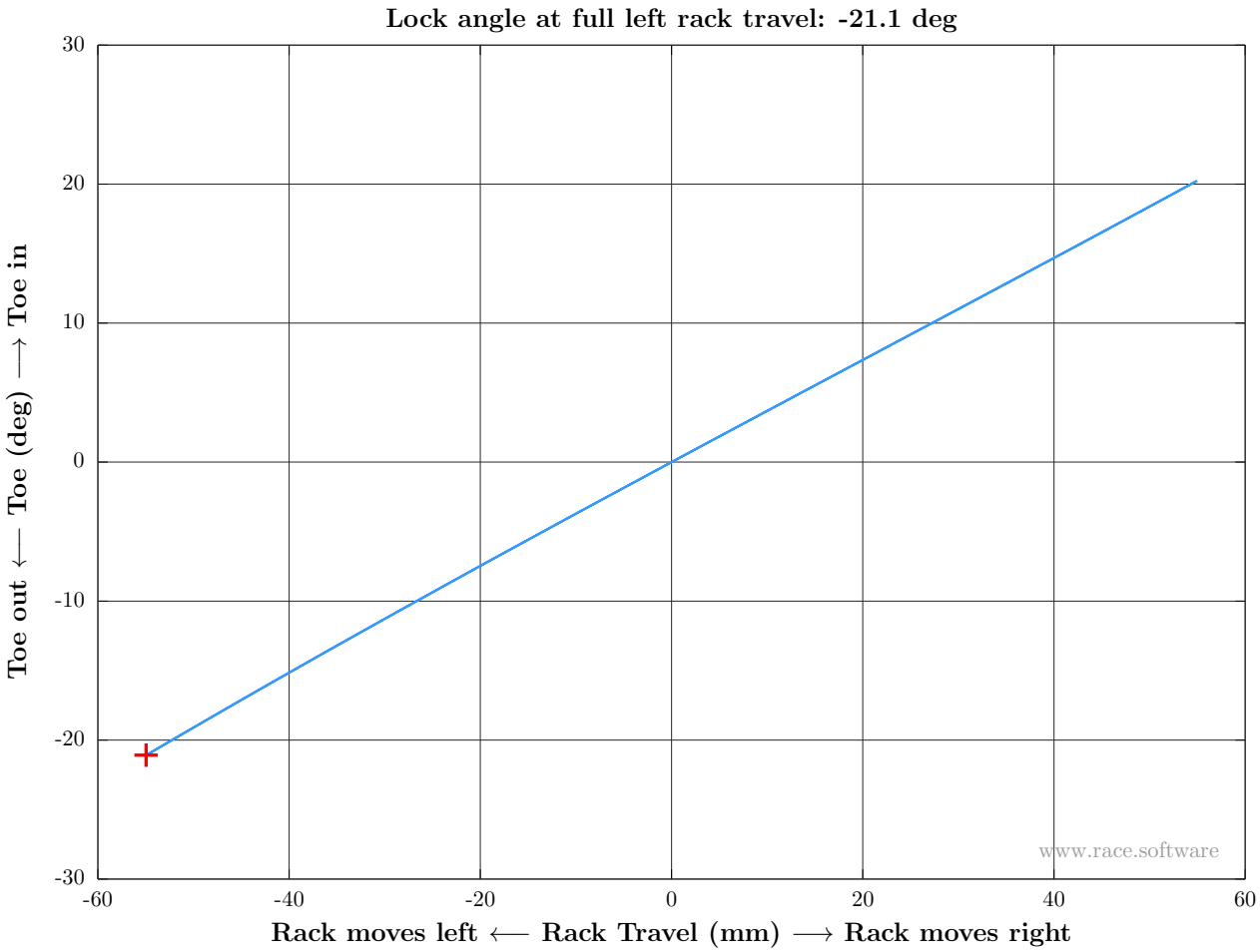

Figure 47: Steering test: Lock angle at full left rack travel

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Figure 48: Lateral test: Roll centre height - wheel load variation

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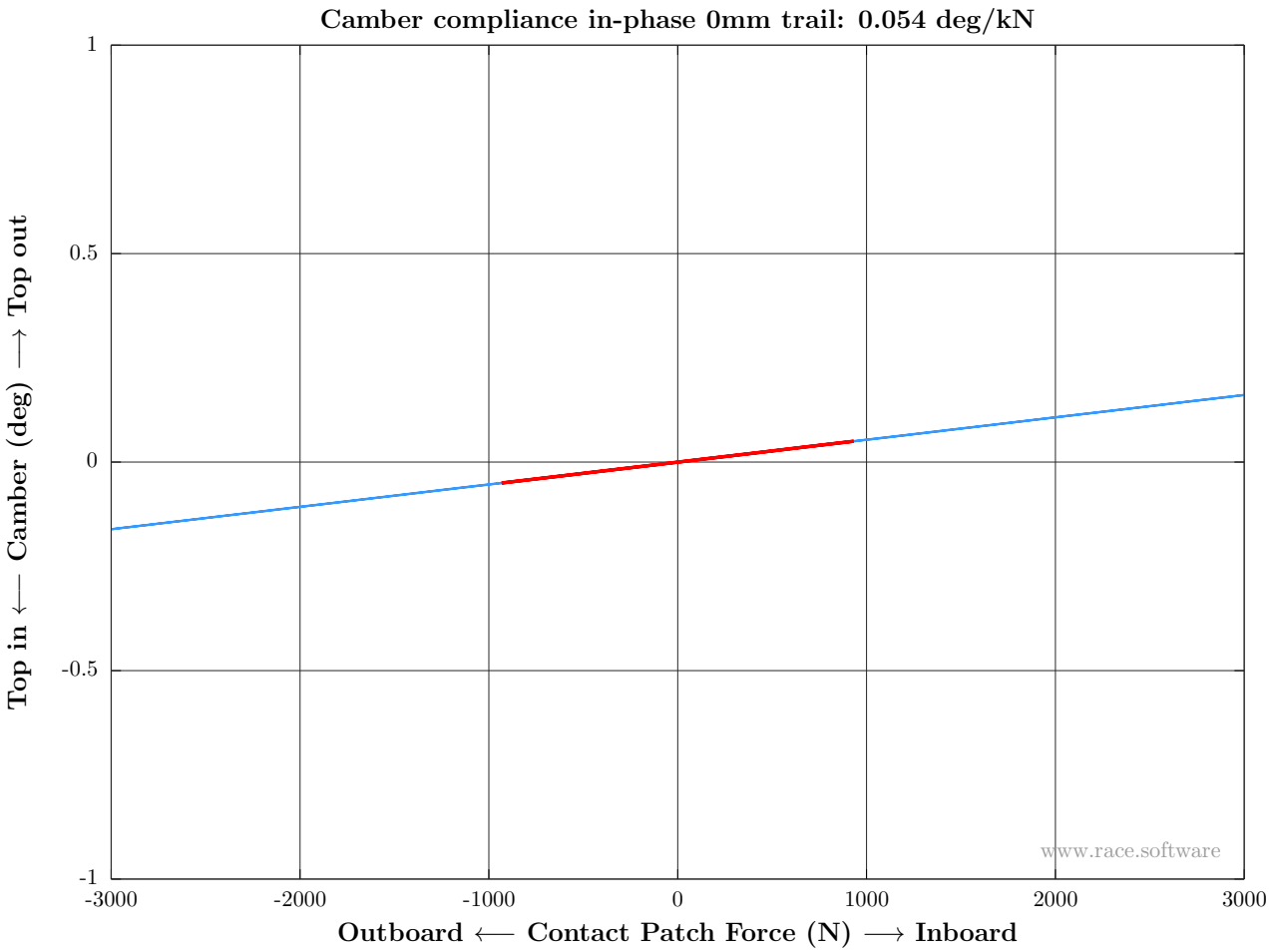

Figure 49: Lateral test: Camber compliance in-phase 0mm trail

⟸ **Back to KPI Summary**

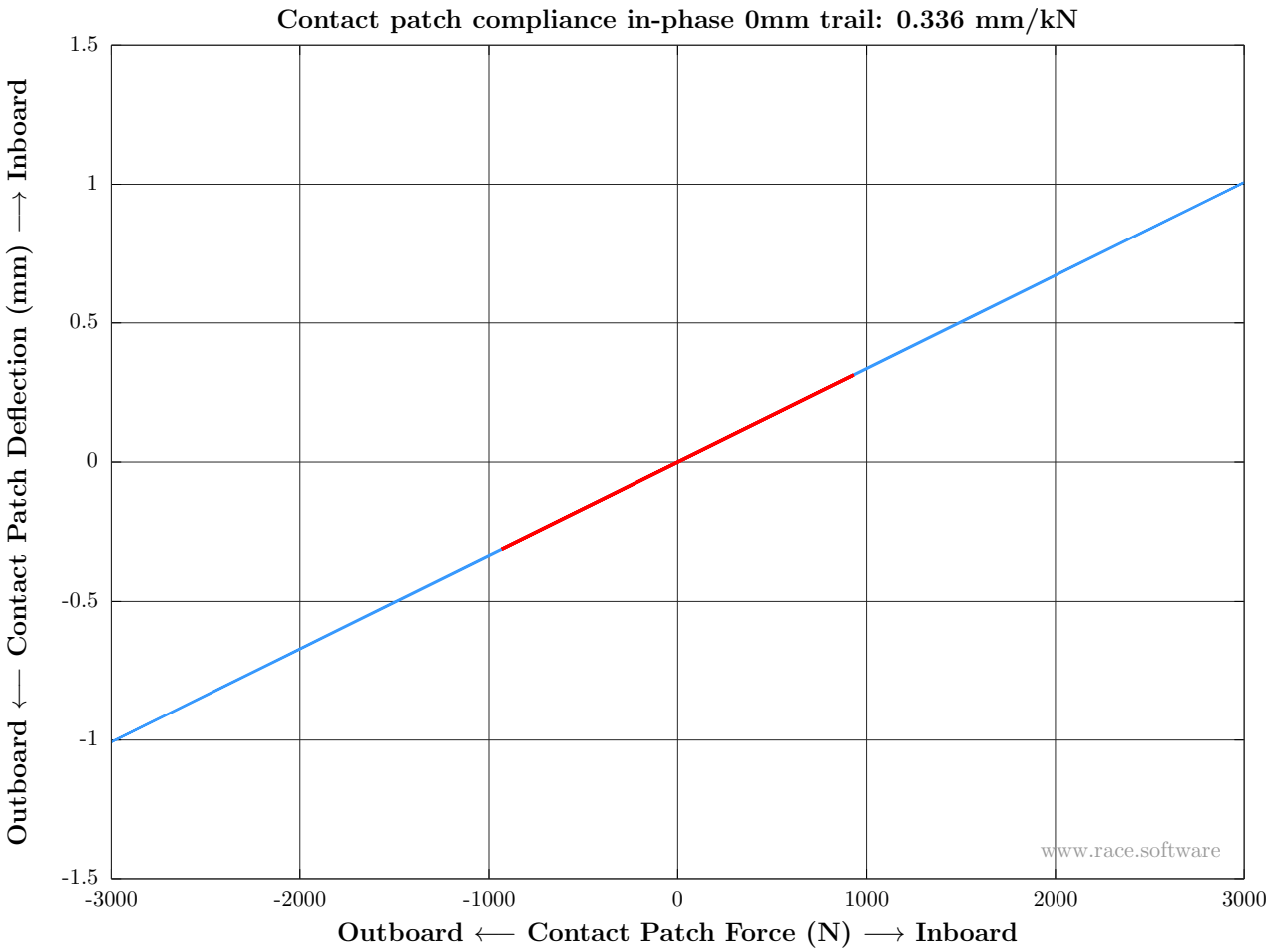

Figure 50: Lateral test: Contact patch compliance in-phase 0mm trail

⟸ **Back to KPI Summary**

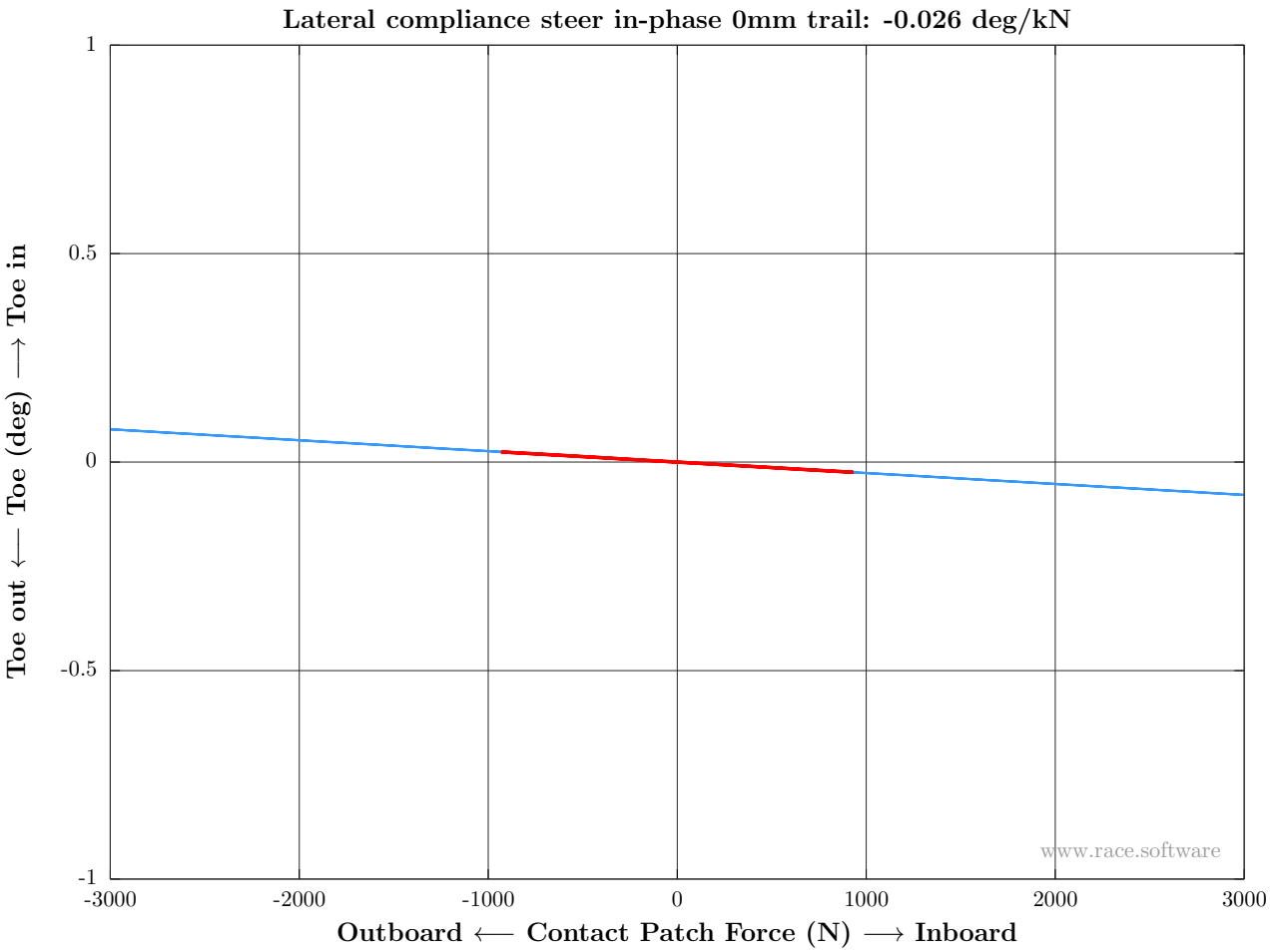

Figure 51: Lateral test: Lateral compliance steer in-phase 0mm trail

⟸ **Back to KPI Summary**

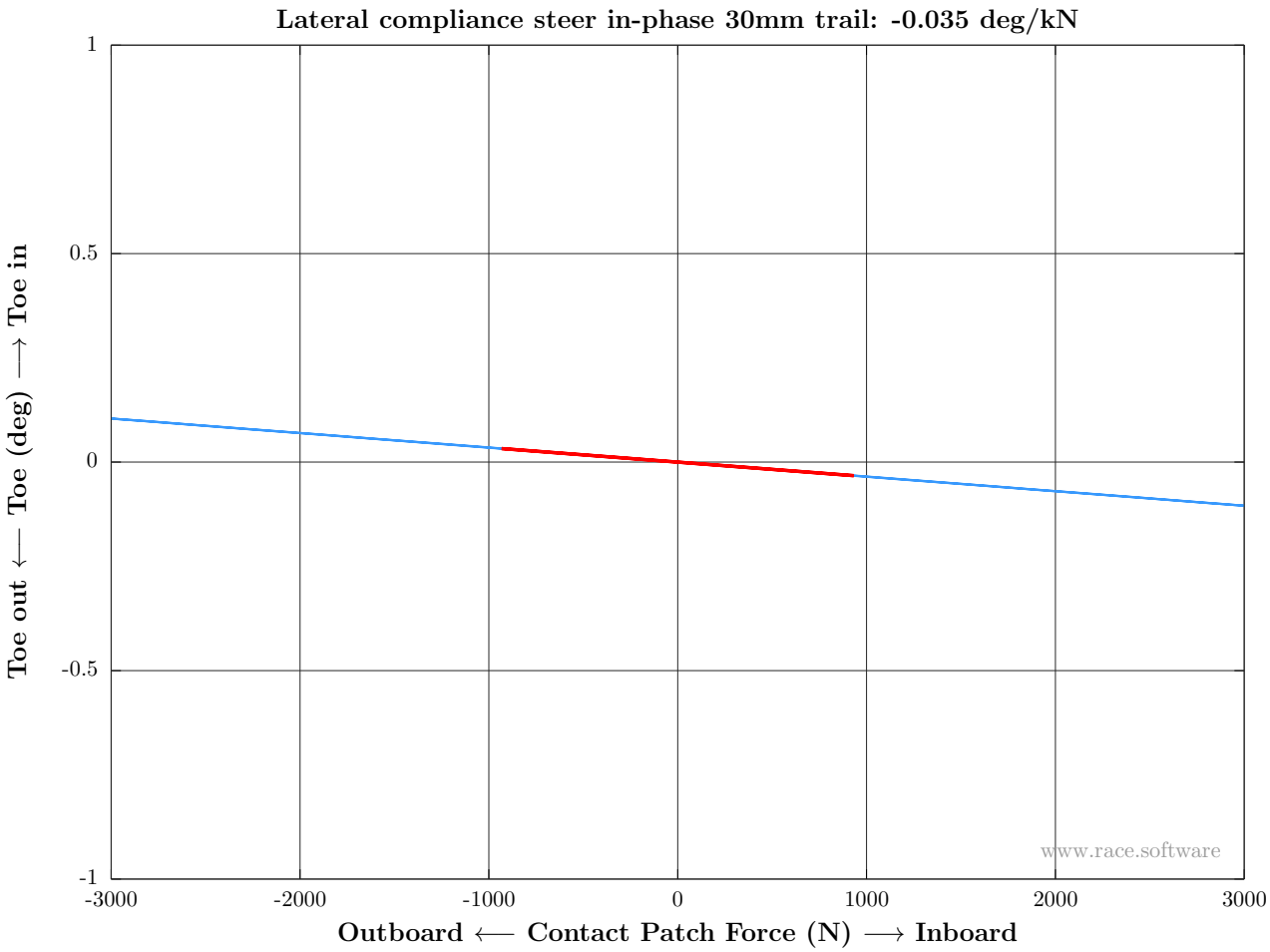

Figure 52: Lateral test: Lateral compliance steer in-phase 30mm trail

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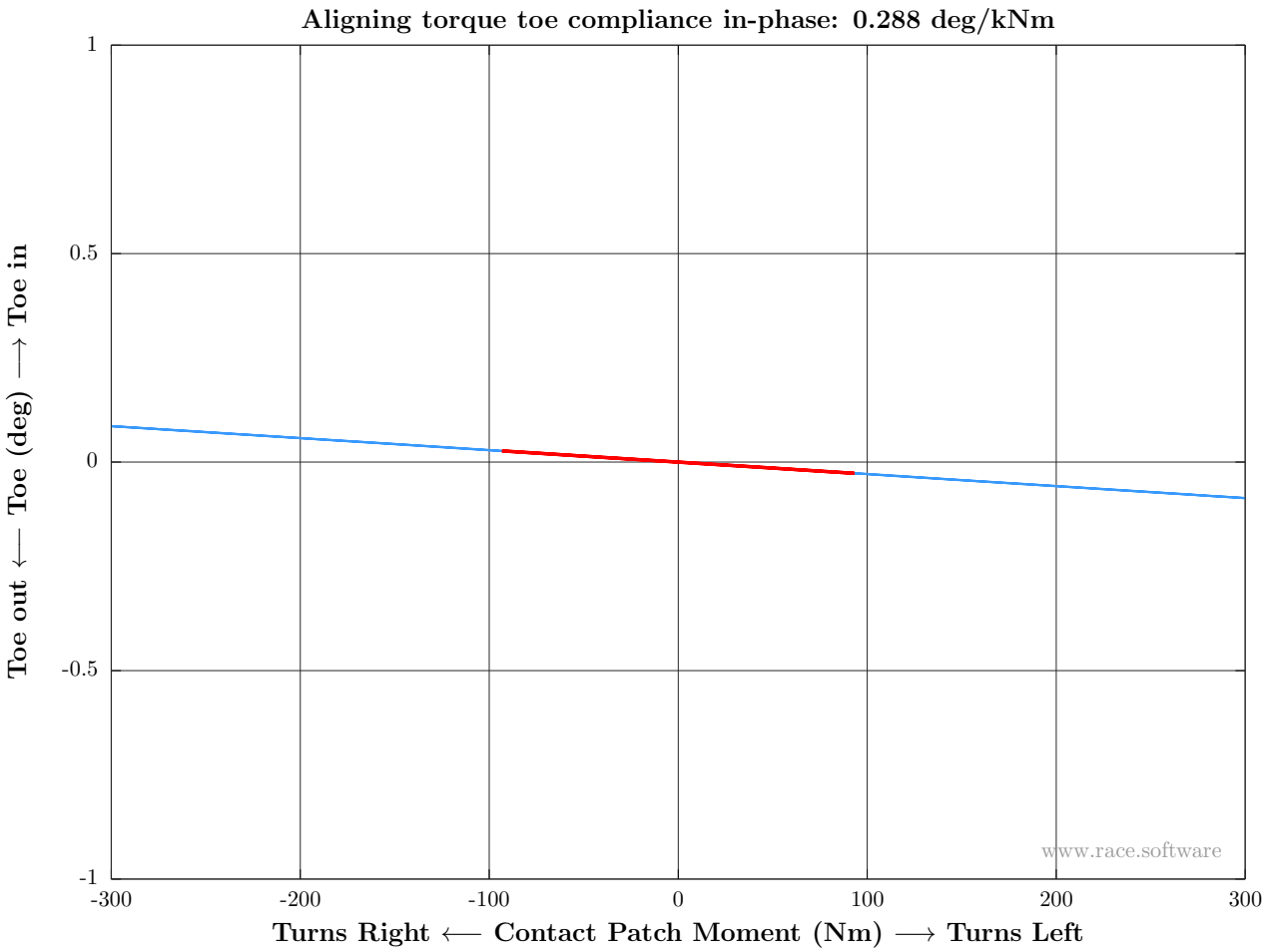

Figure 53: Aligning test: Aligning torque toe compliance in-phase

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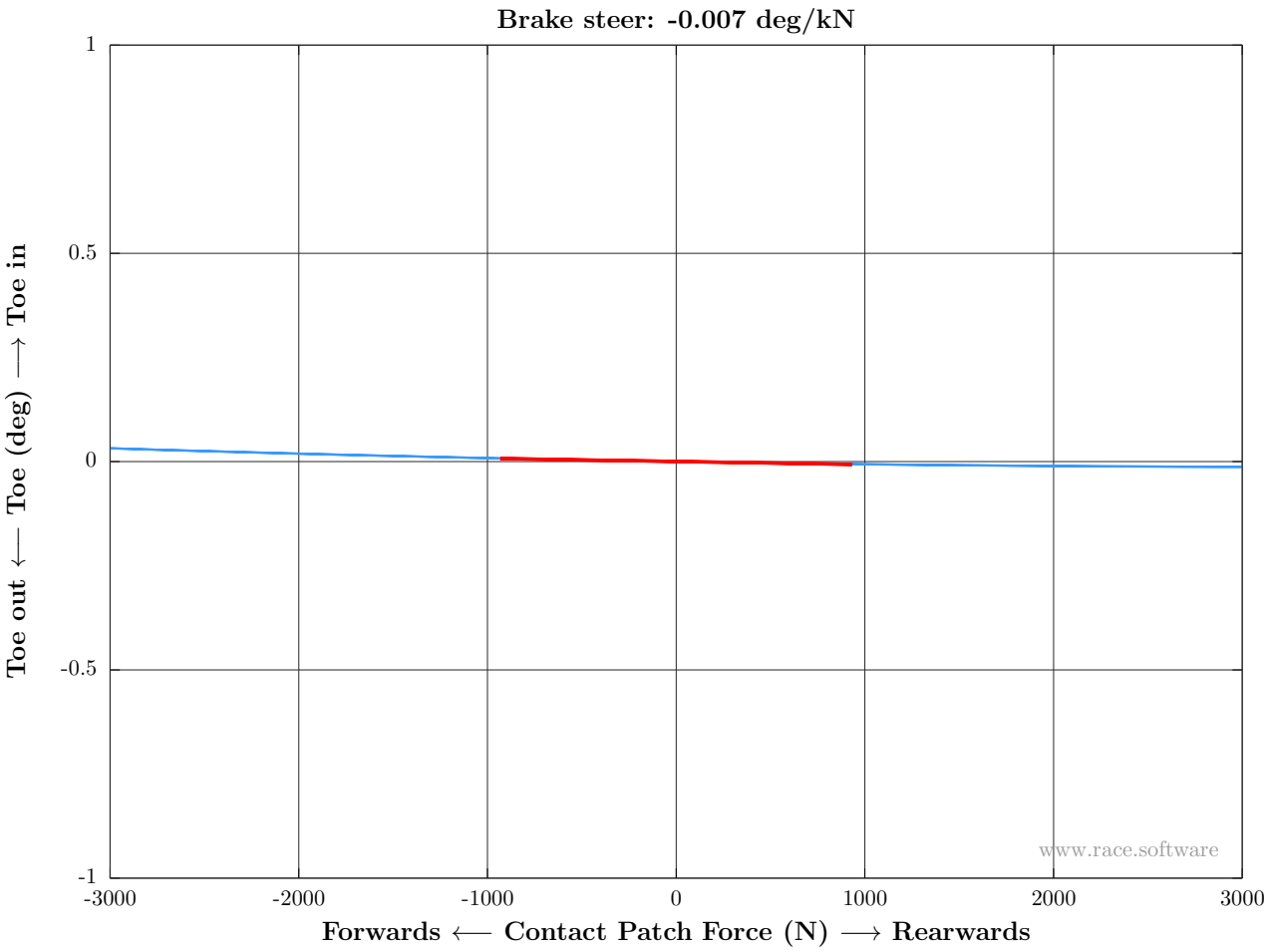

Figure 54: Braking test: Brake steer

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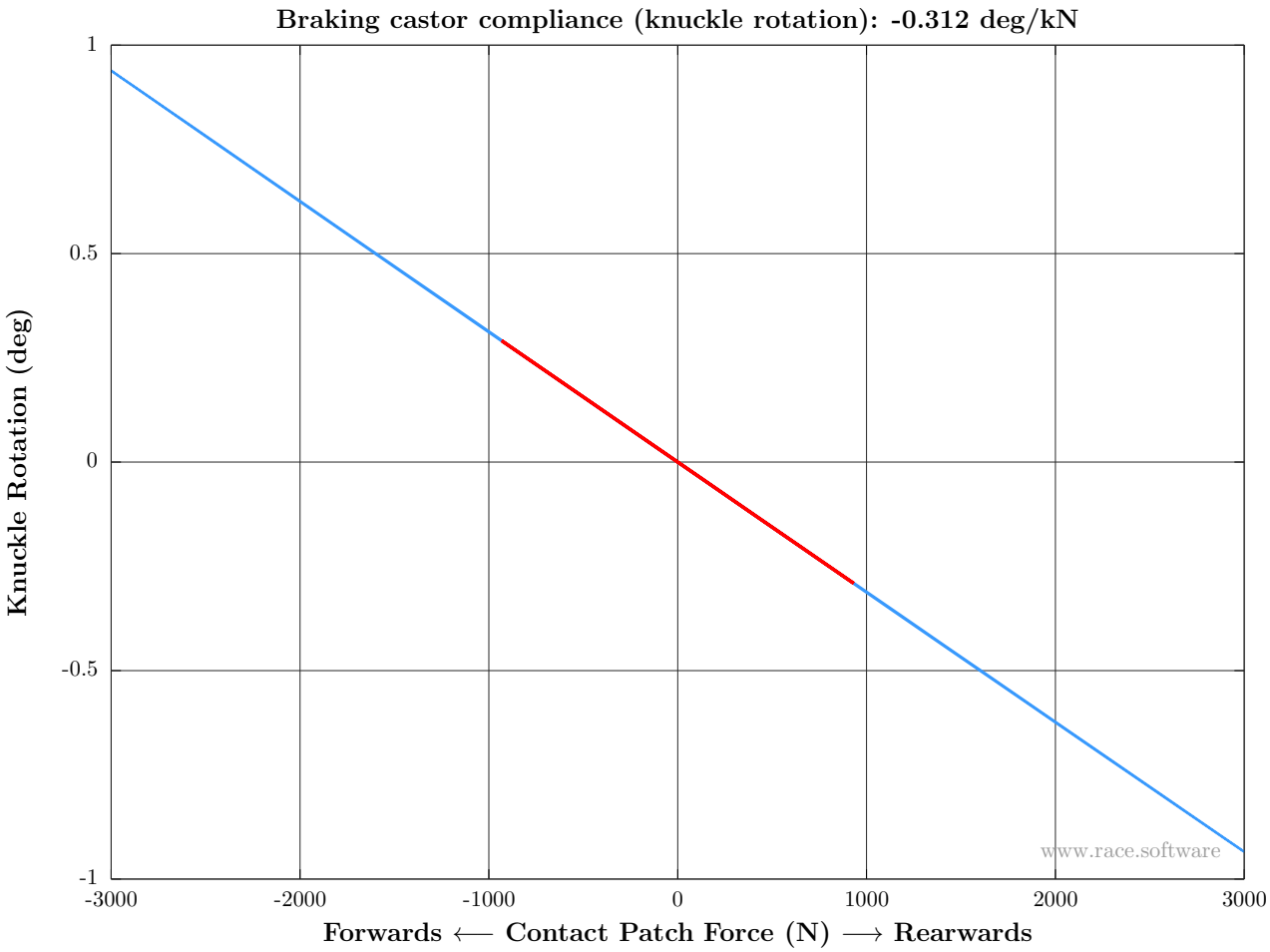

Figure 55: Braking test: Braking castor compliance (knuckle rotation)

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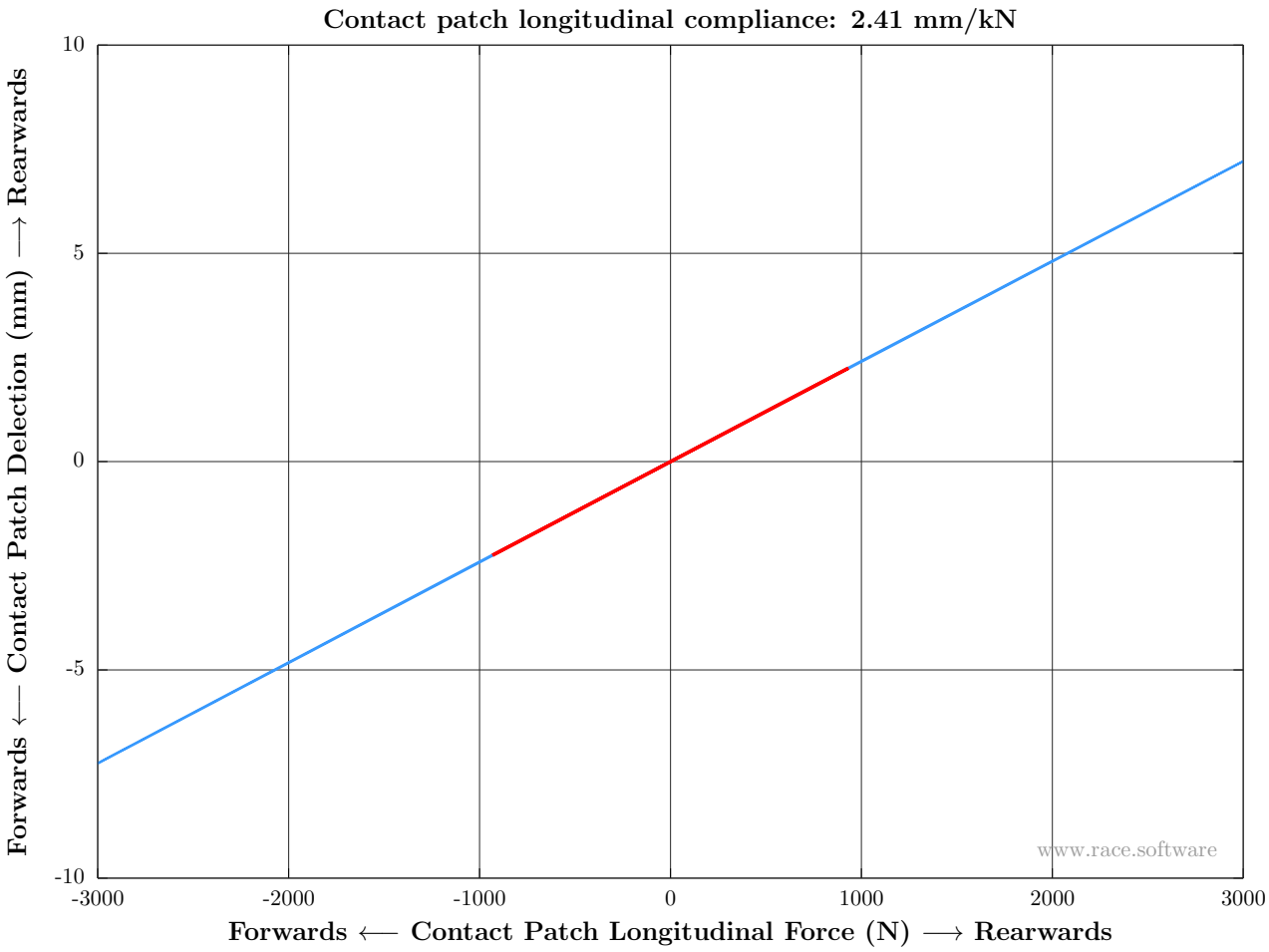

Figure 56: Braking test: Contact patch longitudinal compliance

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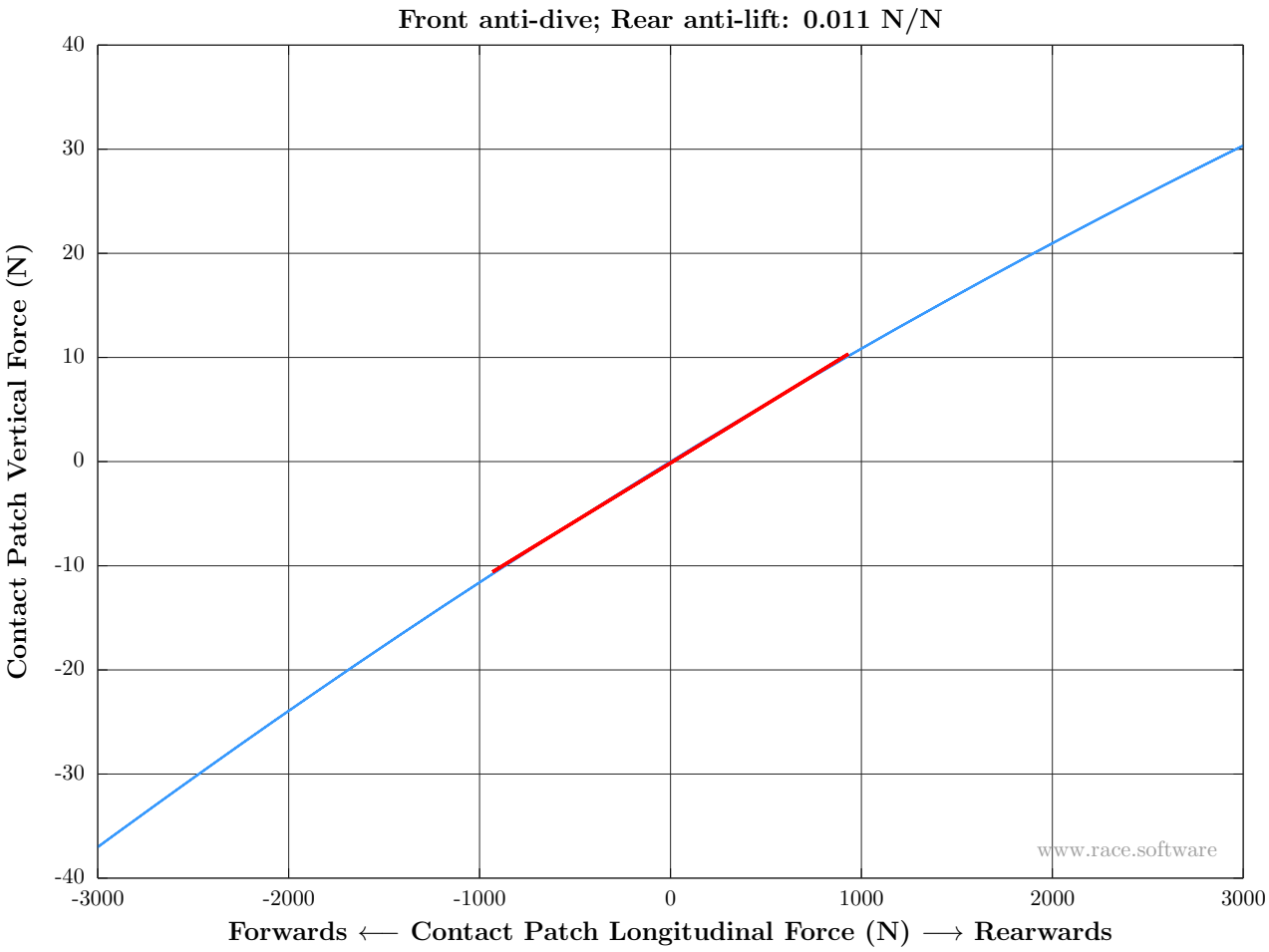

Figure 57: Braking test: Front anti-dive; Rear anti-lift

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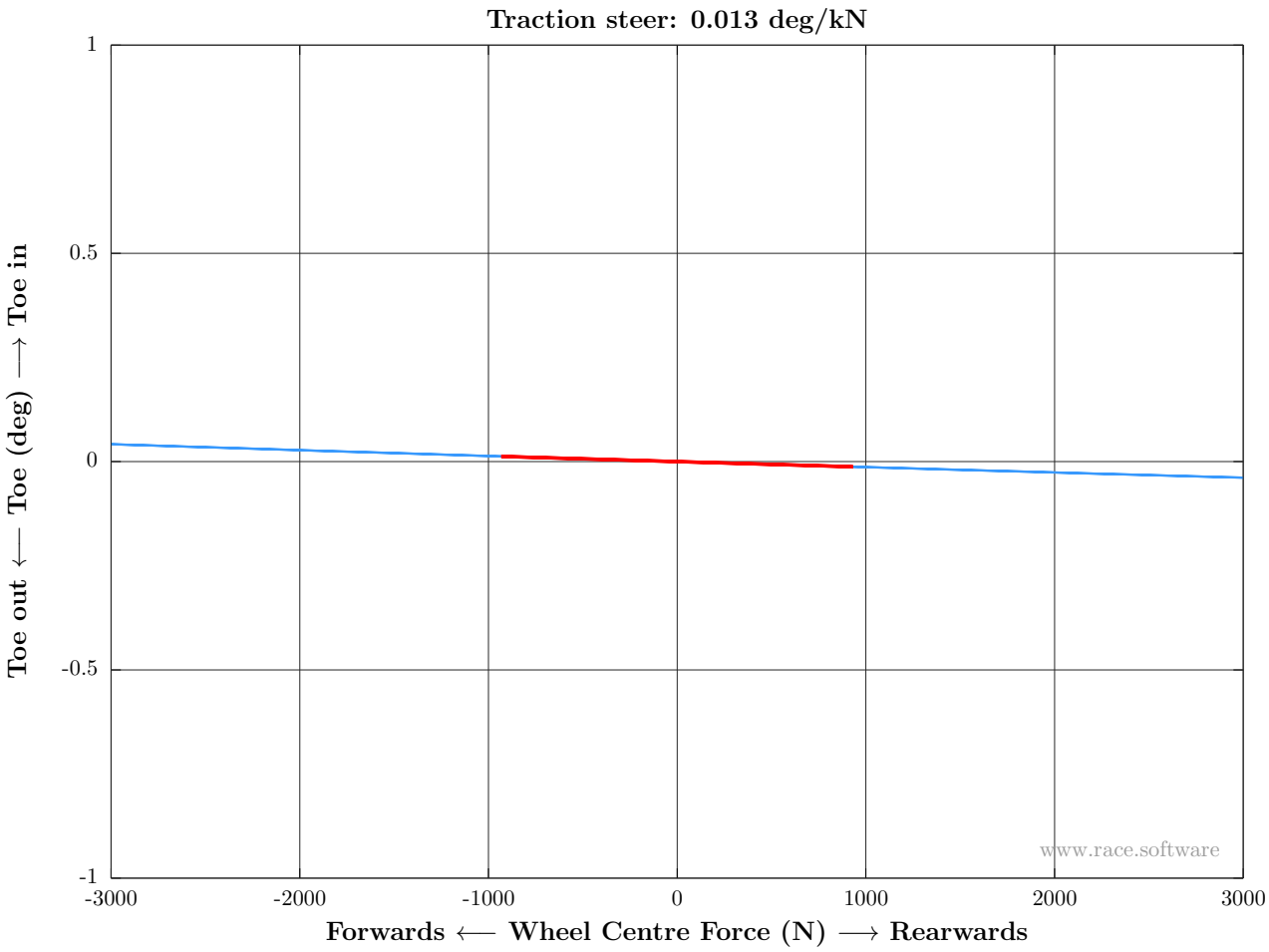

Figure 58: Traction test: Traction steer

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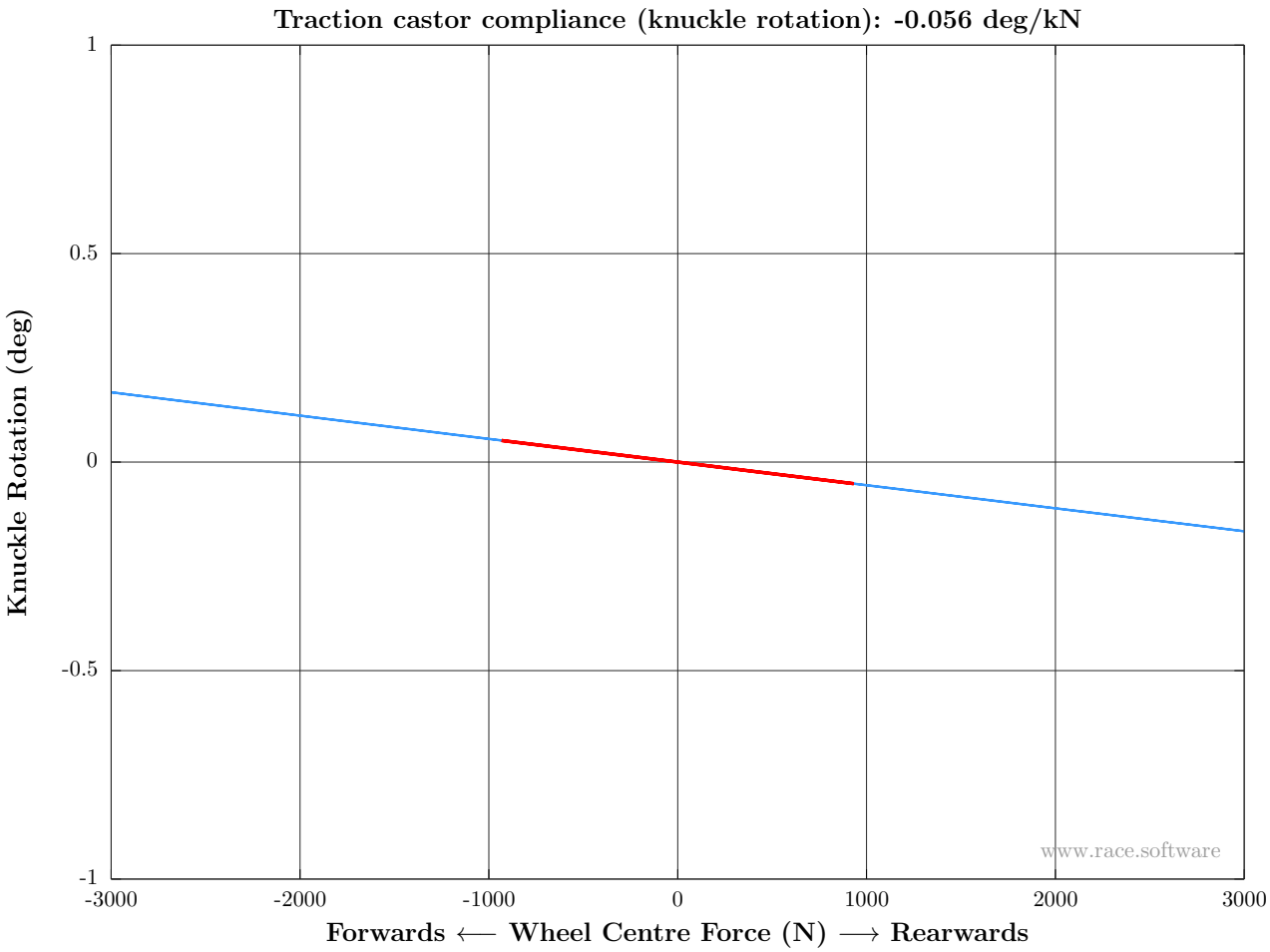

Figure 59: Traction test: Traction castor compliance (knuckle rotation)

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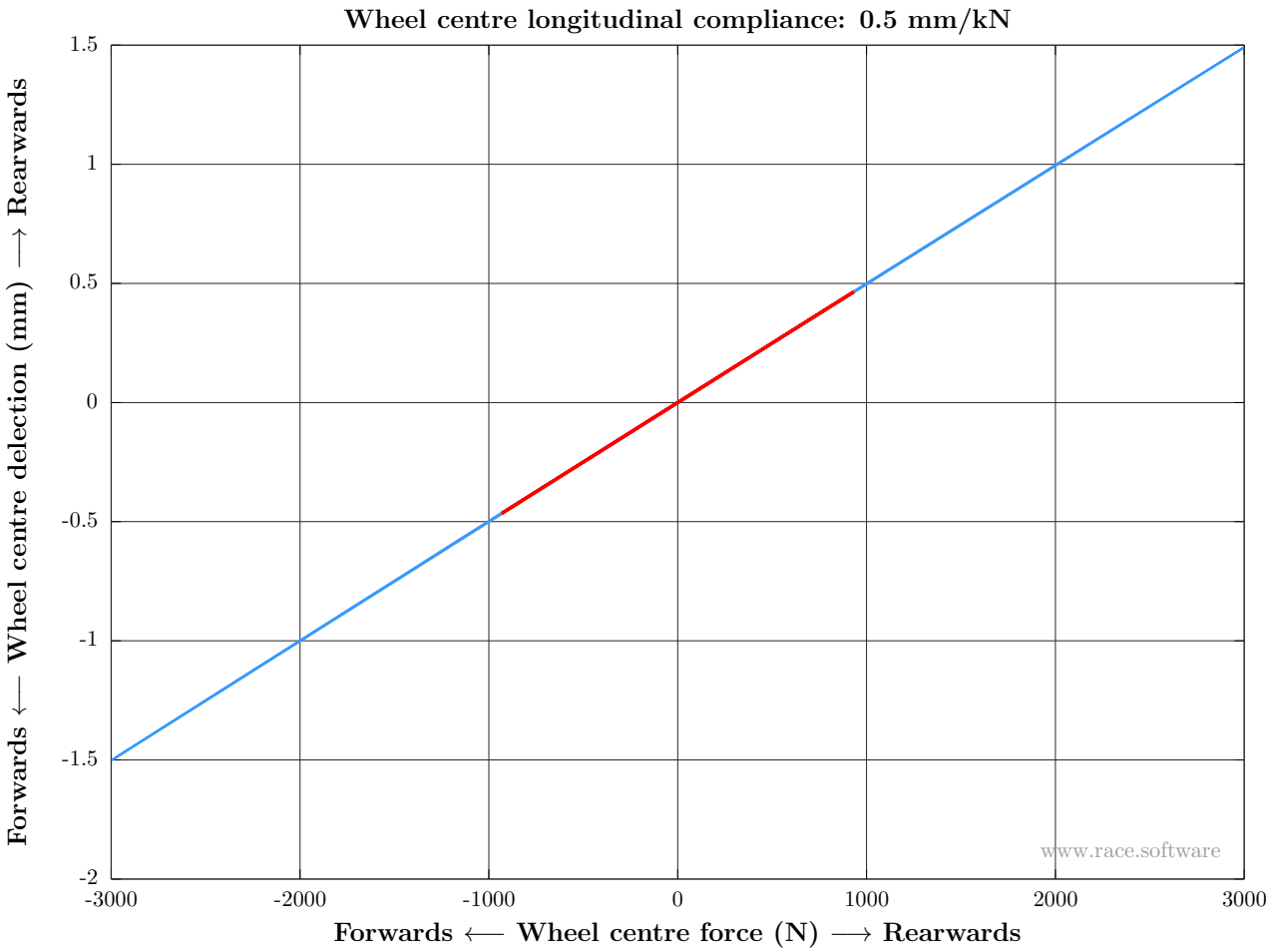

Figure 60: Traction test: Wheel centre longitudinal compliance

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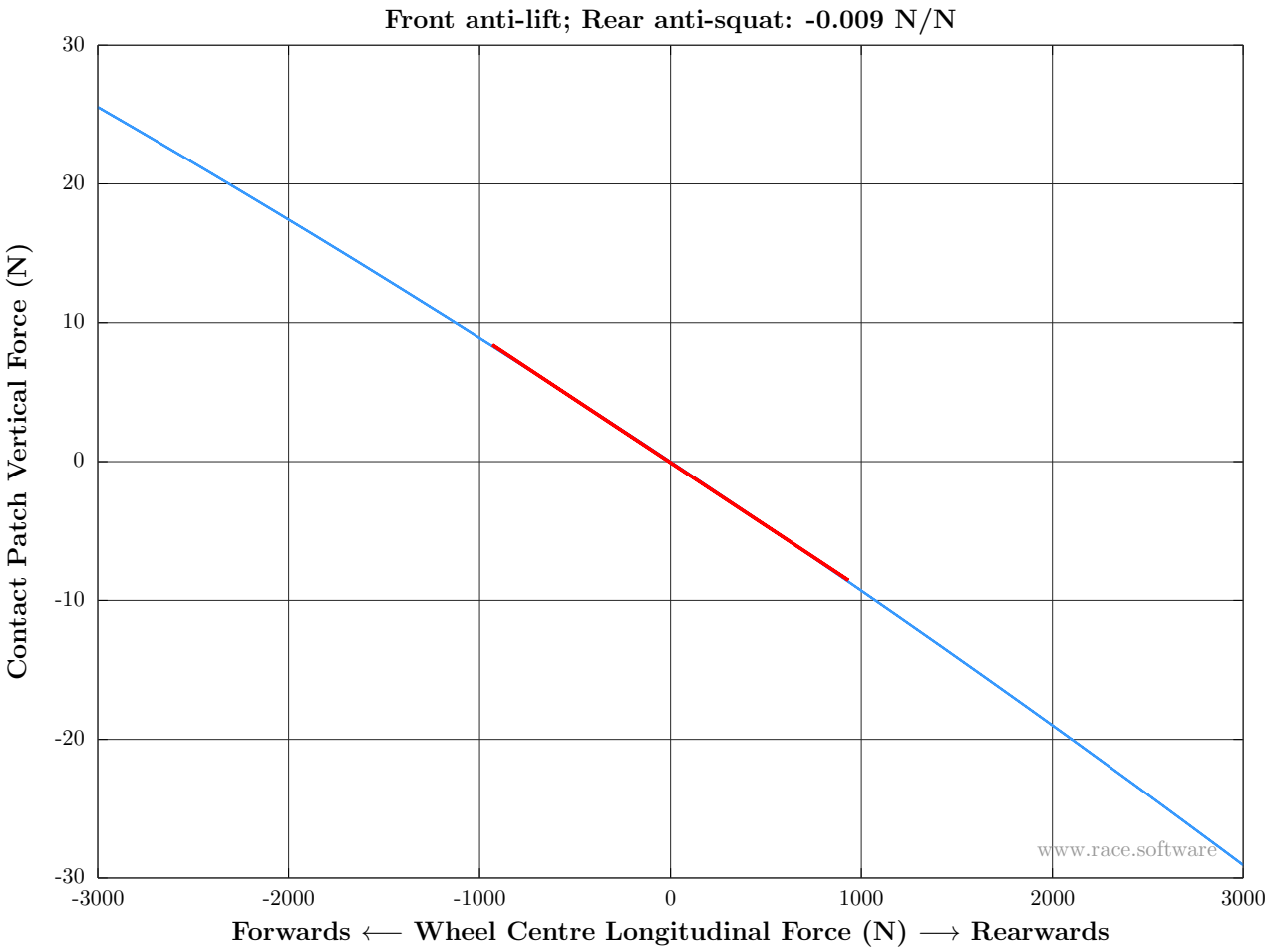

Figure 61: Traction test: Front anti-lift; Rear anti-squat

6 Key Performance Indicator Sign Conventions

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KPI	Unit	Positive metric sign meaning
BRAKING FORCE		
Brake steer	deg/kN	toe in under braking
Braking castor compliance (knuckle rotation)	deg/kN	castor angle increase under braking
Contact patch longitudinal compliance	mm/kN	rearward contact patch deflection under braking
Front anti-dive; Rear anti-lift	N/N	anti-dive (front axle); pro-lift (rear axle)
LATERAL FORCE		
Roll centre height - wheel load variation	N/N	roll centre above ground
Camber compliance in-phase 0mm trail	deg/kN	top of wheel outboard with lateral force
Contact patch compliance in-phase 0mm trail	mm/kN	contact patch deflection inboard
Lateral compliance steer in-phase 0mm trail	deg/kN	toe in with lateral force
ROLL MOTION		
Roll camber	deg/m	top of wheel outboard with bump travel
Roll steer - on centre	deg/m	toe in with bump travel
STATIC GEOMETRY		
Static camber	deg	top of wheel outboard
Static toe	deg	front of wheel inboard (toe in)
STEERING INPUT		
Kingpin inclination - with steer	deg	top of axis is inboard
Castor angle - with steer	deg	top of axis is rearwards
Castor trail - with steer	mm	kingpin ground intersect forward of whl centre
Scrub radius - with steer	mm	kingpin ground intersect inboard of whl centre
Wheel centre longitudinal offset - with steer	mm	kingpin axis is rearwards of wheel centre
Wheel centre lateral offset - with steer	mm	kingpin axis is inboard of wheel centre
Static toelink load	N	toelink in compression
TRACTION FORCE		
Traction steer	deg/kN	toe in under acceleration
Traction castor compliance (knuckle rotation)	deg/kN	castor angle increase under traction
Wheel centre longitudinal compliance	mm/kN	rearward wheel centre deflection for an impact
Front anti-lift; Rear anti-squat	N/N	anti-lift (front axle); pro-squat (rear axle)
TYRE ALIGNING TORQUE		
Aligning torque toe compliance in-phase	deg/kNm	toe change in the direction of the moment
VERTICAL MOTION		
Bump camber	deg/m	top of wheel outboard with bump travel
Bump steer - on centre	deg/m	toe in with bump travel
Bump castor (knuckle rotation)	deg/m	top of wheel rearward in bump
Kinematic wheel centre recession	mm/m	rearward wheel travel in bump
Contact patch lateral migration	mm/m	contact patch inboard migration in bump