SIMPACK User Meeting
18th and 19th May 2011, Salzburg, Austria

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Metro Oslo runs on Holmenkollen – a challenge of running behaviour

?

Christian Brandstätter

Oslo Line 1

Oslo’s Line 1 is a very special metro line. Completely above ground the line winds up 11.4 km from Oslo town to a hill in NW overcoming 470 m difference in altitude with maximum 62‰ gradient and passing the famous Holmenkollen ski jump.

Source: Wikipedia Sansculotte


Station Frognerseteren
Source: Views and News


Station Holmenkollen
Source: Wikipedia Jack Lee

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The FIS Nordic World Ski Championships 2011

When SIEMENS developed the Metro Oslo, the vehicle MX3000 was designed for Lines 2-6 only. Line 1 was still operated with a specially designed vehicle from AEG, called T2000 – but then Oslo was awarded the FIS Nordic World Ski Championships 2011 (23 February to 6 March).

The running of the tournament was based on that none of the 350,000 spectators during the eleven days would use cars, and all would have to use public transport. In order to allow increased capacity on the line, it would either have to be connected to the street tramway, or upgraded to metro standard.

→ SIEMENS challenge: MX3000 has to operate on Line 1

Details: Oslo Line 1

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Comparison of fundamental track alignment data:

	Lines 2-6	**Line 1**
max. twist (basis11m / 2.1m) [‰]	6/9	**8/10**
smallest curve Radius [m]	100	**59**
max. superelevation [mm]	150	120
max. gradient [‰]	55	62

Is a save operation with respect to safety against derailment possible ?

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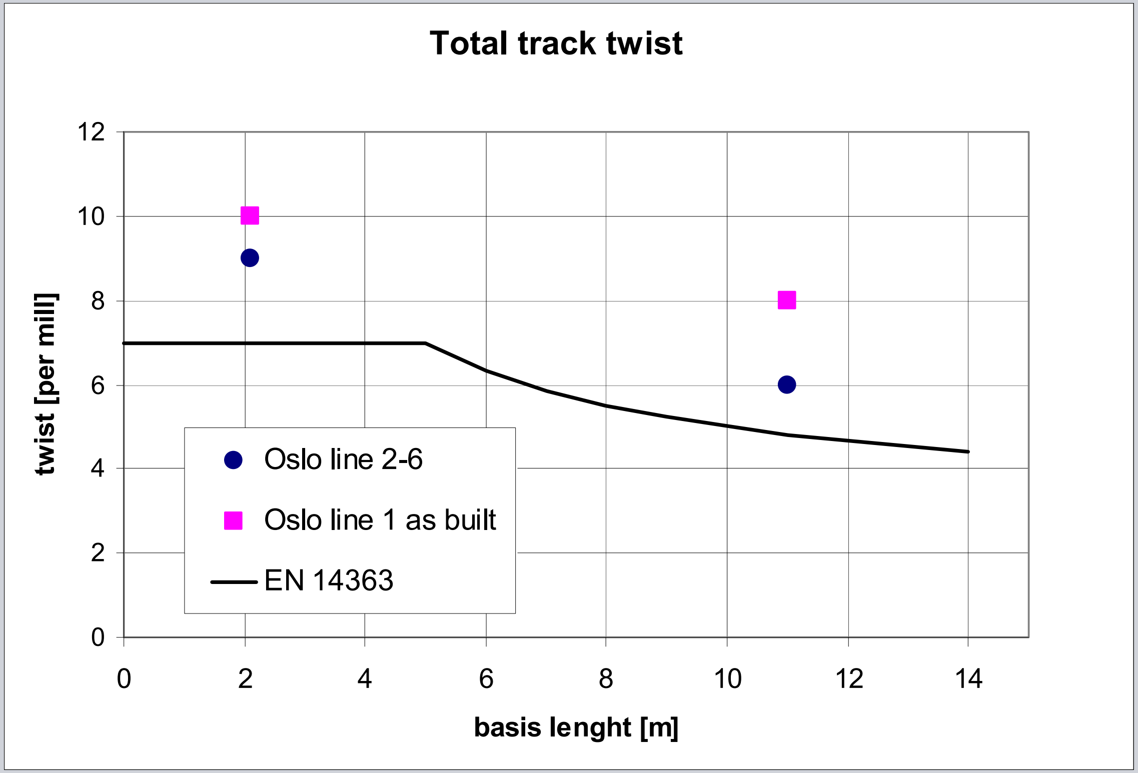
Proof of safety against derailment – standard EN 14363 chapter 4.1

3 Stationary Tests defined,
all based on a total track twist limit for European railways:

g_{lim}= min(7.0, 20/2a+3.0)   with 2a as longitudinal base in m and g_{lim} in ‰.

$2a^{+}$ = 2.1 m
(bogie wheel base)

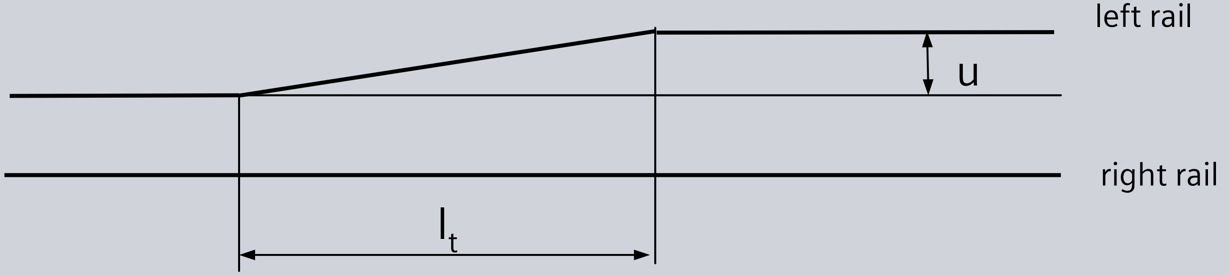
$2a^{*}$ = 11 m
(pivot center distance)



Notes on ramp gradient and total track twist

Ramp gradient:

If a transition curve with linear (not S-shaped) ramp has a length l_t and a superelevation u the ramp gradient is given by: $\frac{|u|}{l_t} \cdot 1000$ [‰]

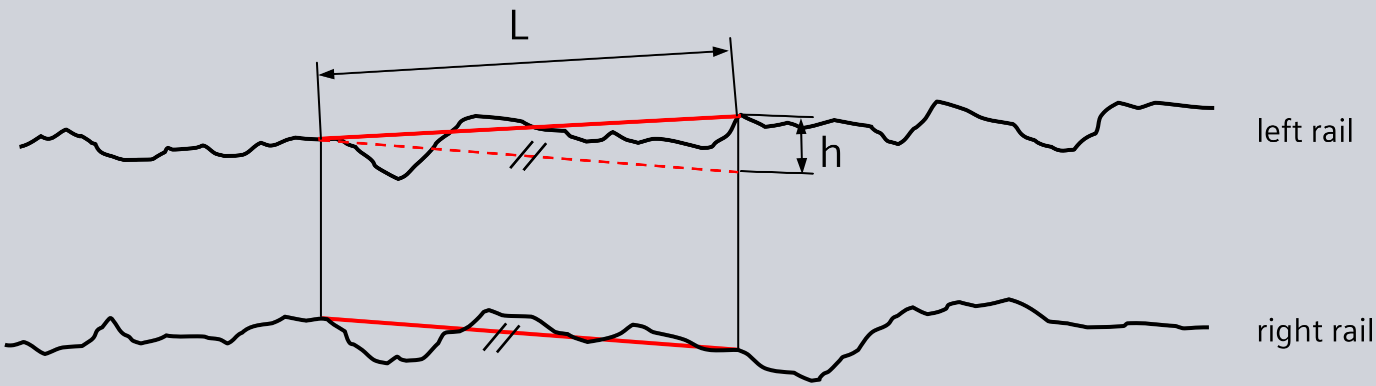


Notes on ramp gradient and total track twist

Total track twist:

Total track twist is the twist of a real track, when measured with a defined measurement length L.
This track twist measured along the track includes all irregularities of the track and twist resulting from ramp gradient.

The track twist measured on basis length L is defined as $\frac{|h|}{L} \cdot 1000 \quad [‰]$



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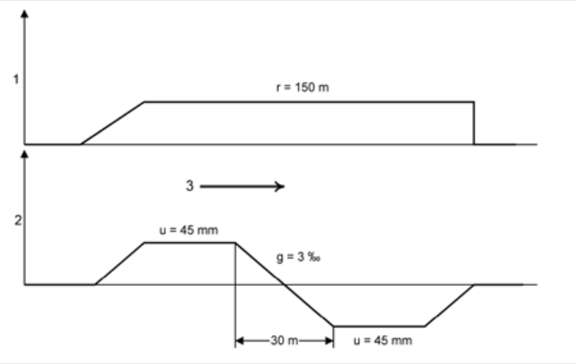
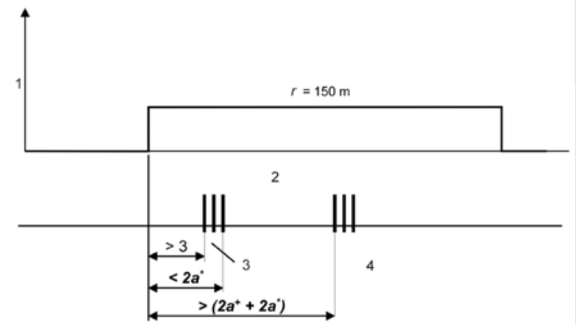
Proof of safety against derailment – standard EN 14363 chapter 4.1

Method 1: test on twisted test track R=150 m,
twist g=3 ‰, superelevation u=45 mm
limit value $Y/Q \leq 1.2$ (Nadal for flange angle 70 °)
flange climbing: $\Delta z_{max} \leq 5$ mm



Method 2: test on twist test rig and flat test track
R=150 m, no twist, no superelevation
test twists $g_{lim}^{*} = 3.36$ ‰, $g_{lim}^{+} = 4.62$ ‰
limit value $Y/Q \leq 1.2$ (Nadal for flange angle 70 °)



OK in Simulation

Proof of safety against derailment – standard EN 14363

Method 3: Test on twist test rig and yaw test rig (X-factor)

$g_{lim}^{*} = 4.82$ ‰, $g_{lim}^{+} = 7$ ‰

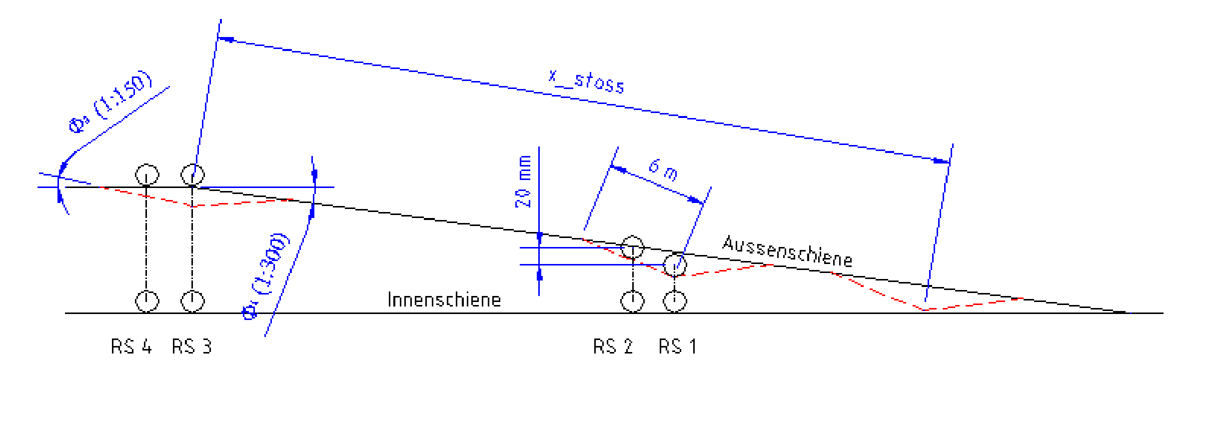
Limits values: $\Delta Q/Q \leq 0.6$, $X \leq 0.1$ at R_{min}

Simulation (Annex B):

$R \geq 200$ m	150 mm cant
200 m > $R \geq 150$ m	100 mm cant
150 m > $R \geq 100$ m	50 mm cant

ramp gradients 1/300 (3.33 ‰)
20 mm dip with semi-span of 6 m
low speed

gauge widening
friction coefficient of 0.32
limit value $Y/Q \leq 1.2$

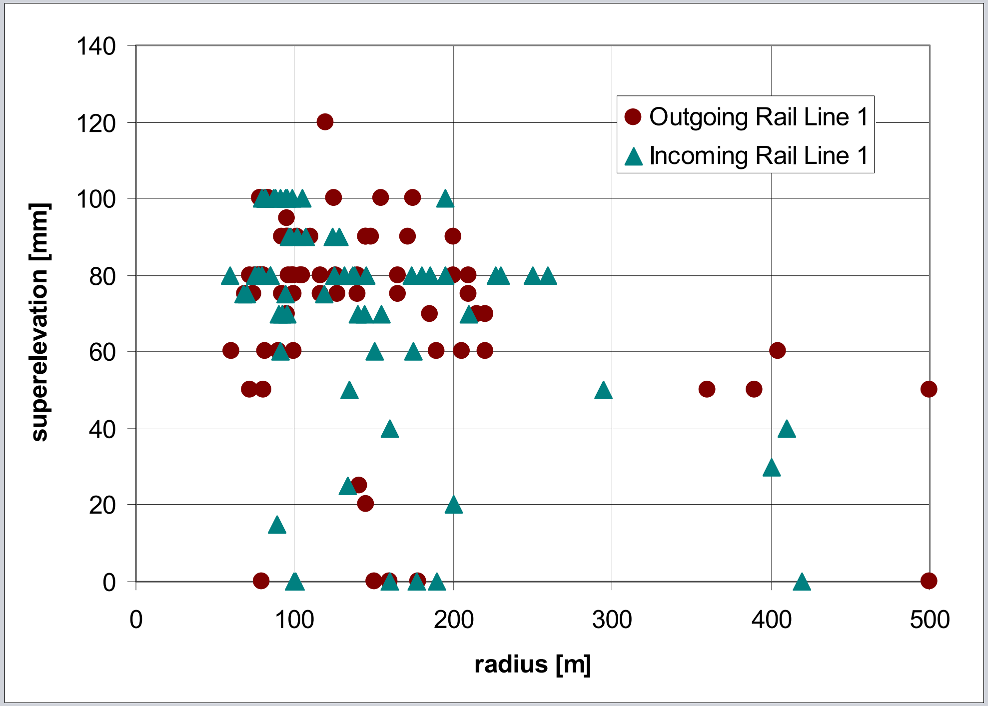


Proof of safety against derailment – standard EN 14363

Method 1-3:

The influence of cant excess is <u>not considered</u>.

"It is assumed that the reduction in the guiding forces in larger curve radii have a stronger influence on the safety against derailment than the higher offloading of the guiding wheel due to the higher allowed cant excess in these radii"



Assumption of EN 14363 is not fulfilled for Line 1.

Adaption of methods 1-3 to Line 1 conditions possible but not proven.

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Proof of safety against derailment – standard EN 14363

EN 14363 On-Track Test:

Running Safety 5.3.2.2

The safety-critical limit for the quotient of a leading wheel is:

$(Y/Q)_{max,lim} = 0.8$ Scope: curved track with radius of $R \geq 250$ m

“In transition curves it is recognized that higher values than 0.8 may be encountered. The maximum limit value of 1.2 (for flange angle of 70°) applied for the quasistatic testing according 4.1 shall be respected. Actually in transition curves no specific limit can be specified, however it shall not exceed 1.2 and in the case where 0.8 is exceeded each case shall be investigated and justified”

Alternative Solution: Simulation of real track scenarios at maintenance limit

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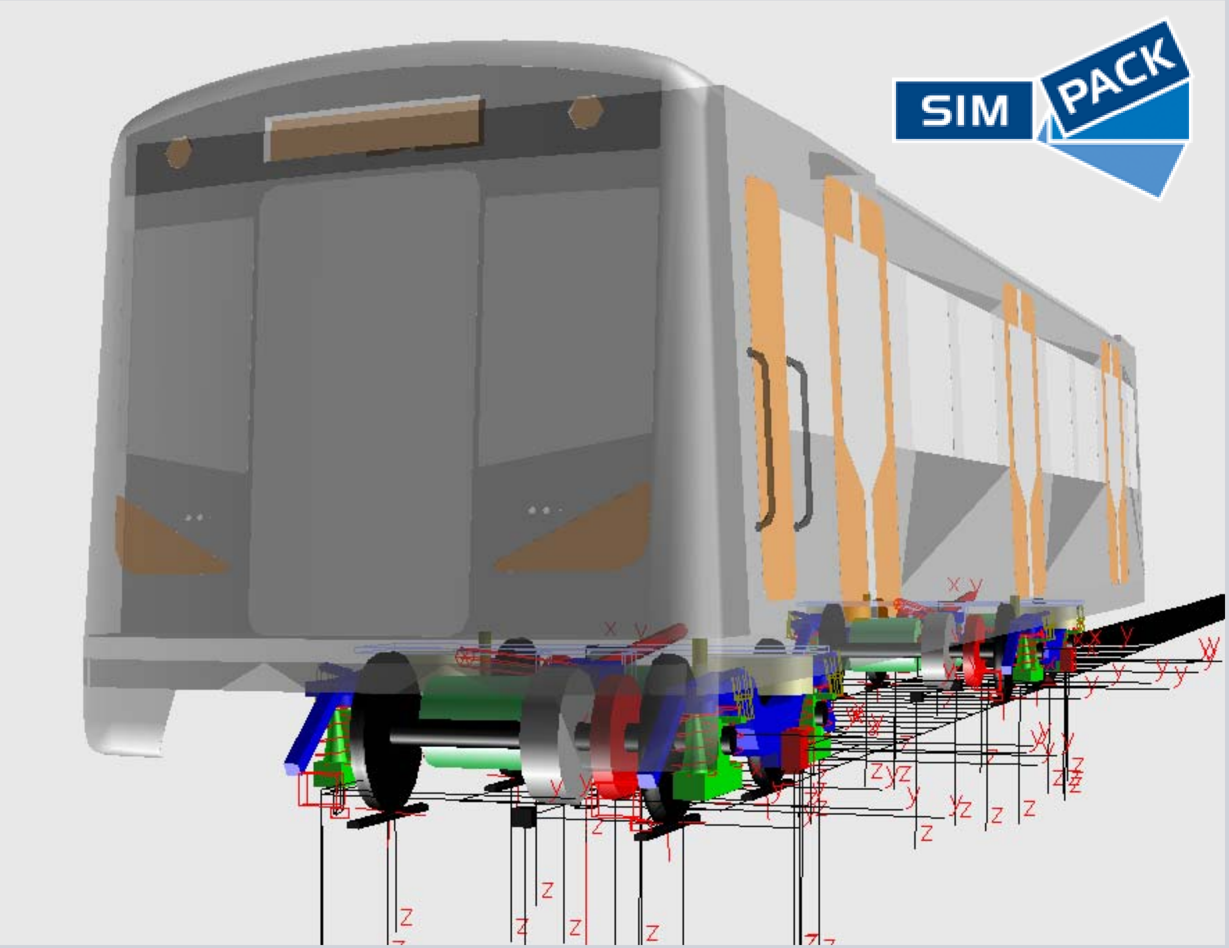
Simulation Model



SIMPACK model:

Standard modeling depth:
- 57 rigid bodies
- 97 force elements
- 55 degrees of freedom
- 134 states

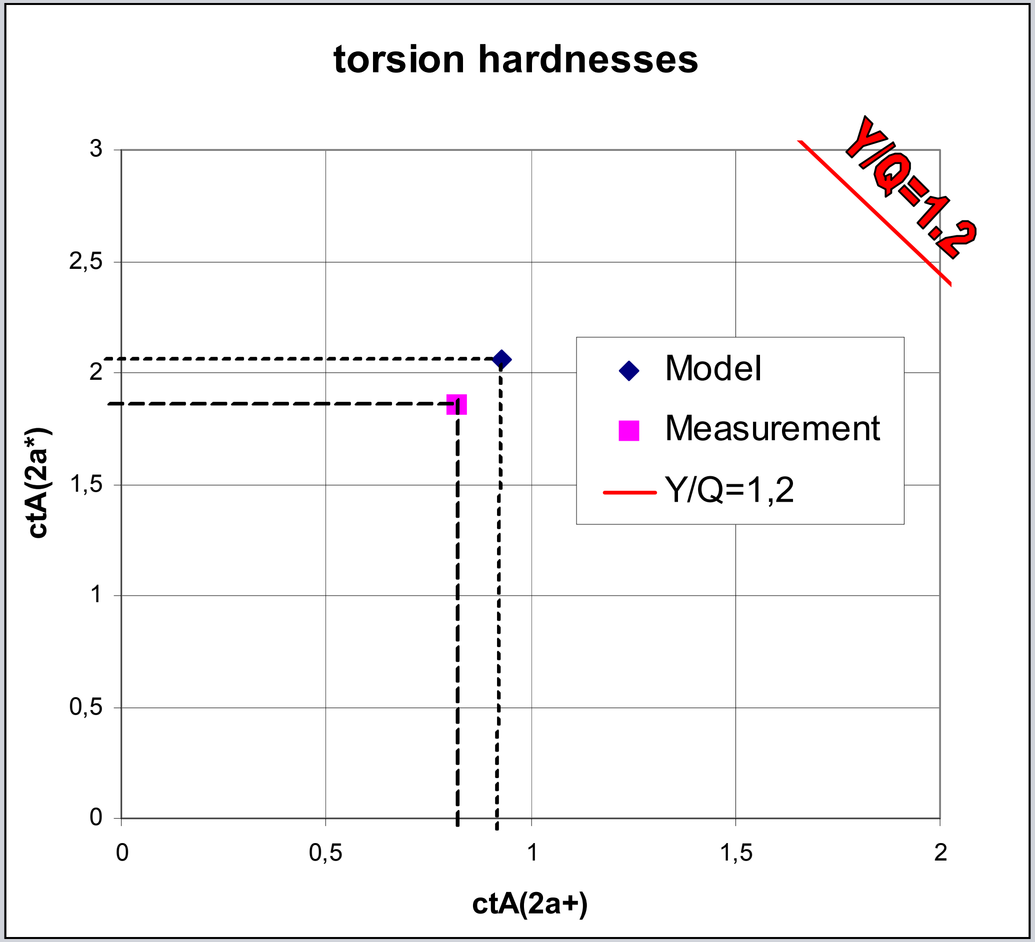
torsional stiffness of car body is considered

Simulation Model

Verified simulation model - performed tests for homologation:

Static tests:
- car body leveling test
- wheel load test
- twist test

On track test:
- gauging
- ride quality
- stability



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Track definition

Track definition in SIMPACK :

radius, ramp gradient, superelevation -> straight forward (curve passing)

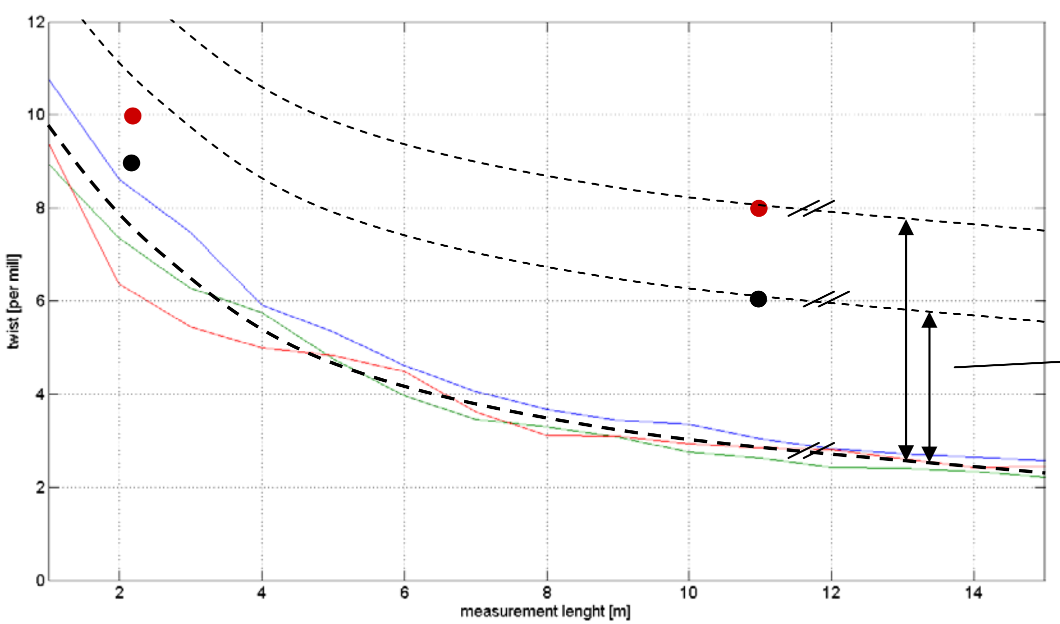
Track twists $g_{lim}^{*} = 8$ ‰ and $g_{lim}^{+} = 10$ ‰ have to occur simultaneously in curve exit transition ramp.

2 possibilities for definition:
- track with no excitation, dip in exit transition ramp
- track with excitation

For calculation of safety against derailment the track alignment and the track excitations have been superposed that way that the total max. twists (superelevation ramp gradient and excitation) on 11 m and 2.1 m basis are reached at the beginning of the curve exit transition ramp. The worst case position has to be found by variation.

Track definition

Track twist: comparison of three worst track data in our track database



- Line 1
- Lines 2-6

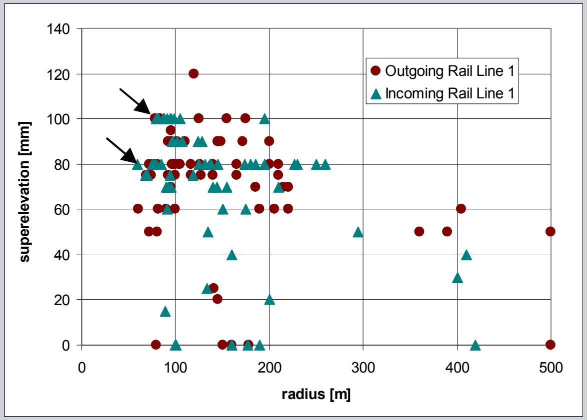
ramp gradient

typical characteristics, combination g_{lim}^{*} = 8 ‰ and g_{lim}^{+} = 10 ‰ not plausible

Worst case simulation scenario

The most critical case is the one, when the wheel with the lowest wheel load is the leading curve outside wheel.

- empty front car running in reverse direction
- left handed curve
- deflated air spring
- smallest curve radius with highest superelevation
- new wheel profile
- low speed

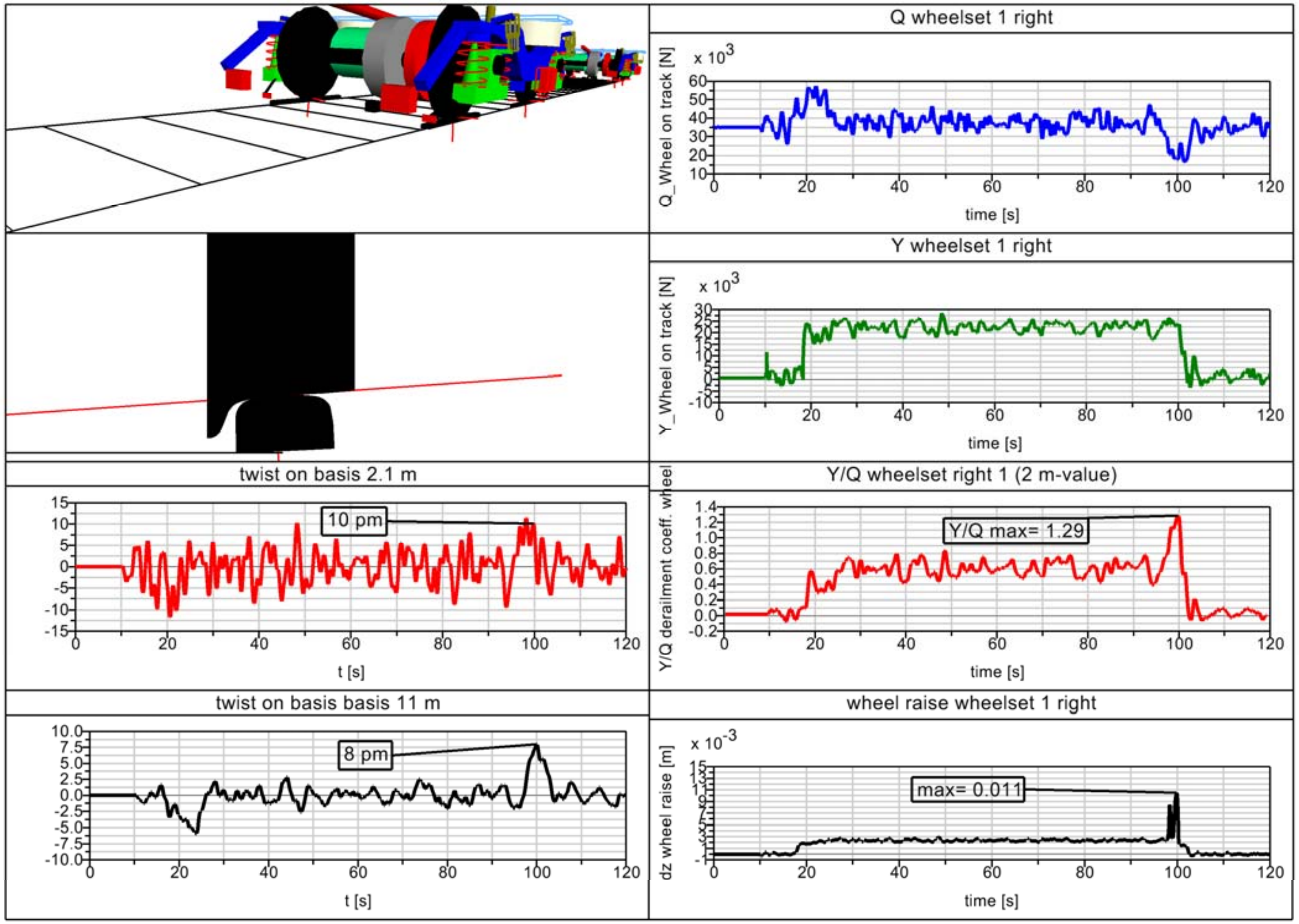


Results: R=59 m, u=80 mm Y/Q=1.28, flange climbing=10.5 mm

R=78 m, u=100 mm Y/Q=1.3, flange climbing=11 mm

Vehicle is not safe !

Worst case simulation scenario



Oslo_R59.mpg Oslo_R78.mpg

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Possible measures

<u>Vehicle:</u>

- changes in suspension elements
- ballast
- active systems
- …

<u>Operation:</u>

- no operation on emergency springs

<u>Track:</u>

- increase curve radii -> not possible
- reduce track twists (individually)
- reduce superelevation

} one or a combination could be a solution

Track measurement showed : actual max twists < limit values

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Required track modification

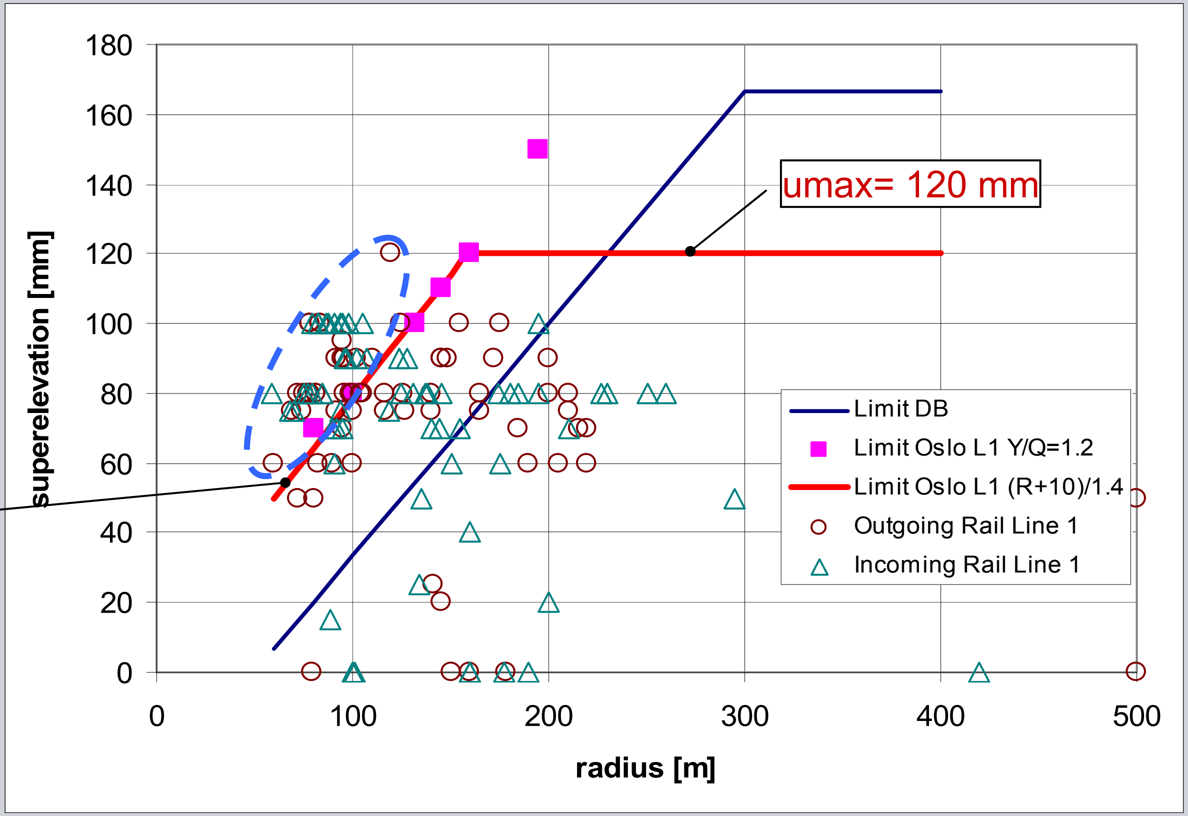
Task: finding a limitation for superelevation u=f(R) via SIMPACK Parvar

- with twist limits 8 ‰ / 10 ‰ -> no acceptable result

- with twist limits 6 ‰ / 9 ‰ as on lines 2-6 ■

u_{max}=(R+10)/1.4

u to high



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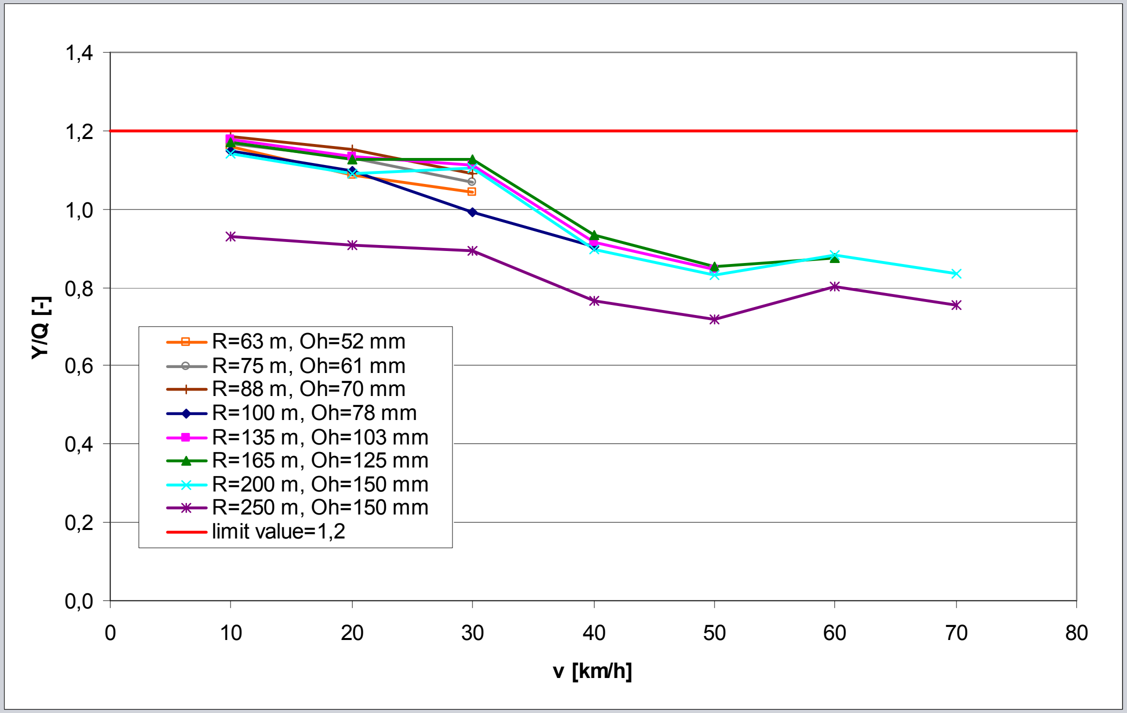
Homologation

Finally: Check Y/Q and flange climbing at all speeds, curve radii, payloads, wheel/rail profiles,braking with magnetic rail brake (one-sided), …
Example:



Method and simulation results have finally been accepted by TÜV and authority NRI (Norwegian Railway Inspectorate) in time.

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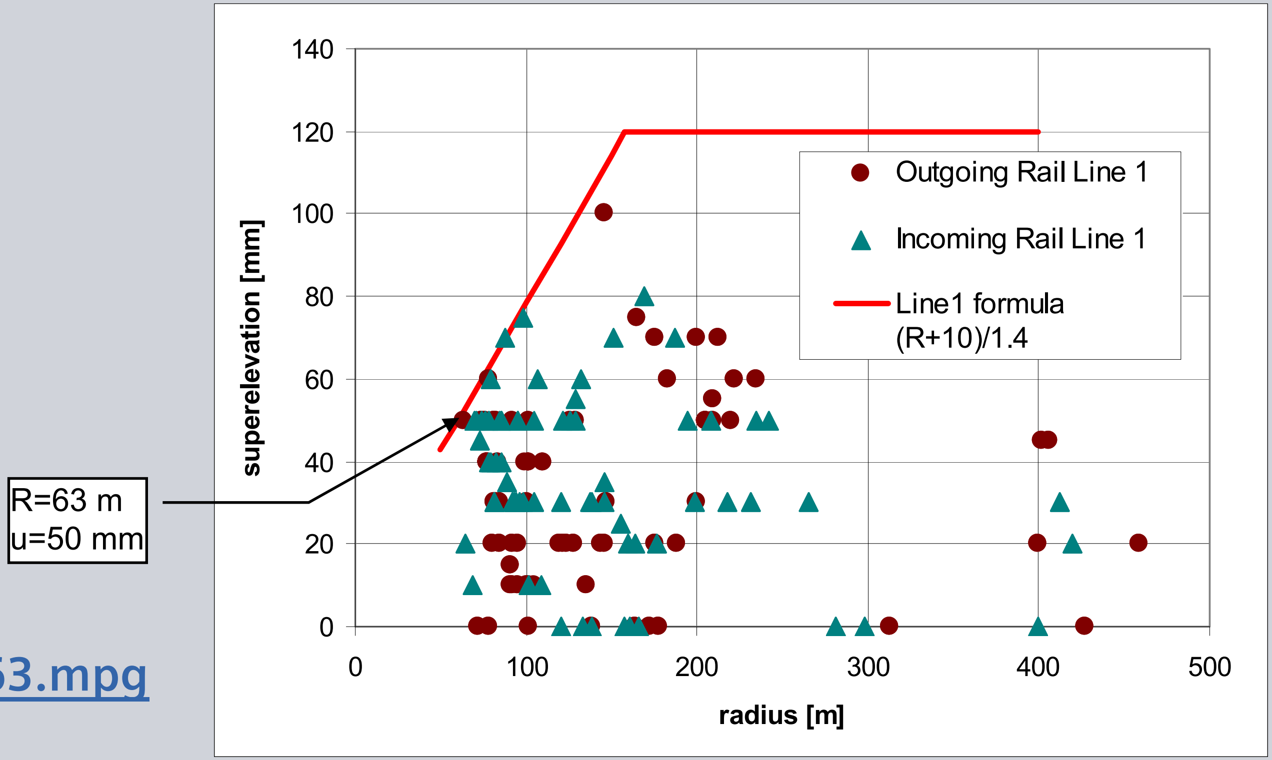
Final status Line 1

Affected curves for need of reduction of superelevation: 41

In the course of modification of the power supply of Line 1 also the required changes on alignment and speed adaptions where done by the operator.

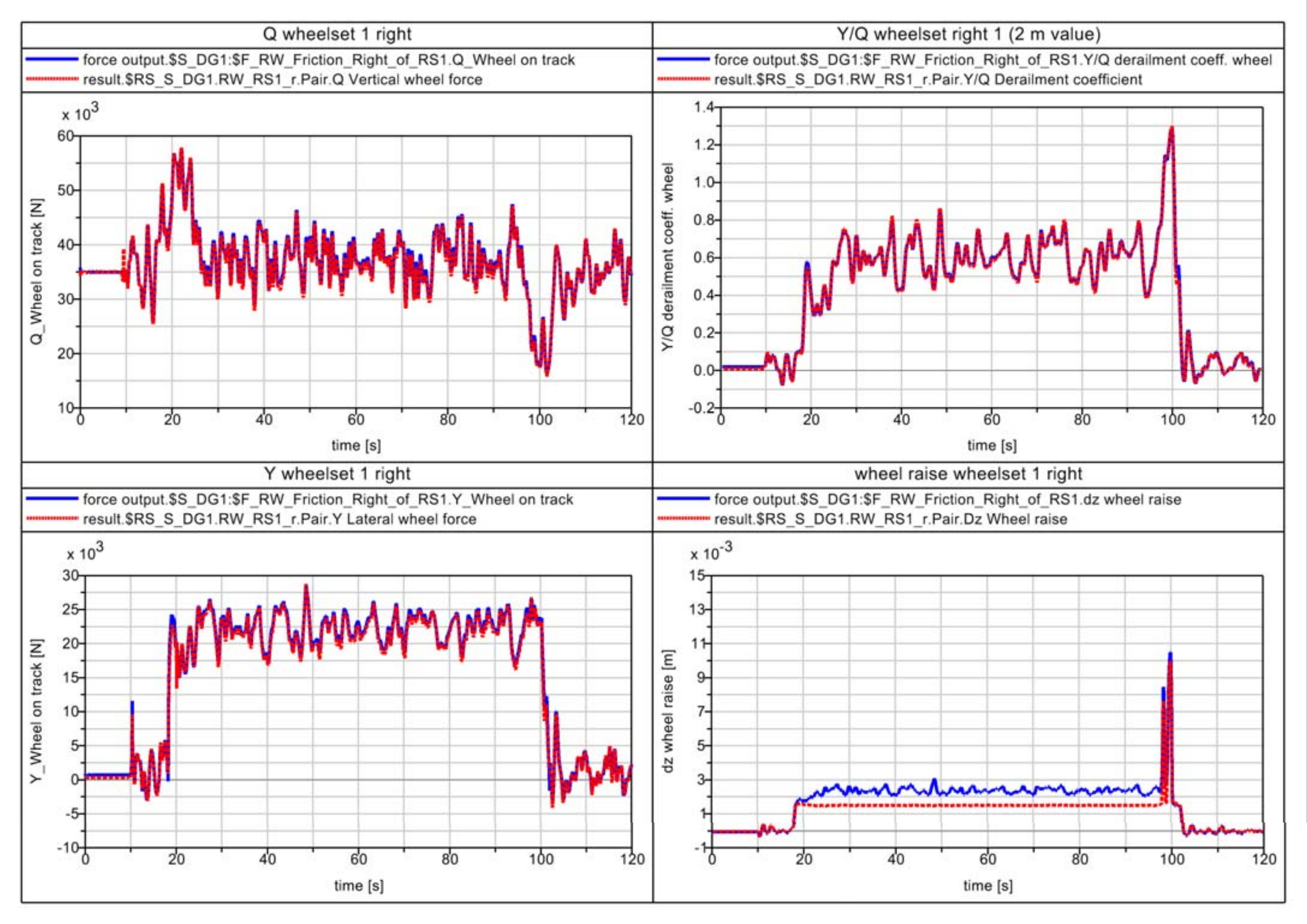


Oslo_R63.mpg

Comparison to SIMPACK RAIL

Initial situation:

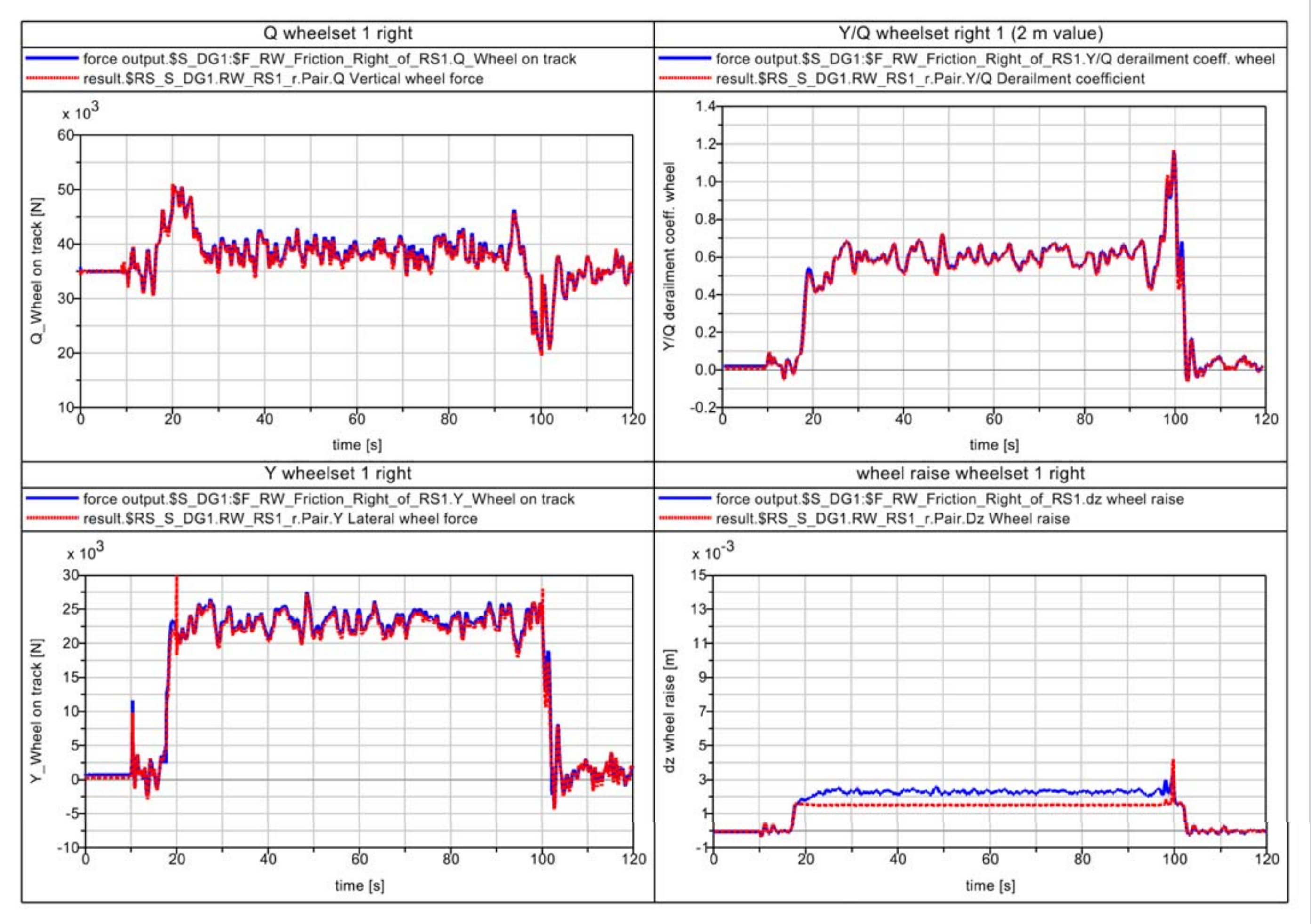
R=59 m
u=80 mm



Comparison to SIMPACK RAIL

Final situation:

R=63 m
u=52 mm



Very good agreement between old Wheel Rail and RAIL

Praxis

On 6.12.2010 the new Line 1 was opened by his Excellency King Harald V. of Norway.

The extensive operation of the MX3000 at the FIS Nordic World Ski Championships 2011 did not show any problems and approved our approach.

A total ride up on Line 1 can be seen on http://nrk.no/holmenkollbanen/
(Warning: duration 45 min - for railway freaks only)

Thank you for your attention.