Call for Simulations: Dynamic Wheel/Rail Benchmark
Single Wheelset without Friction

Benchmark Status

This problem is proposed by the FRA/DTT Cooperation Team to help analyze differences between several codes using either elastic normal calculations or constraint equations.

Even though reducing the model complexity to only one axle, analysis of its behavior would still be complex because mixing essential mechanisms: rolling, calculations of normal contact forces and dynamic equations. This very simple Benchmark (one single wheelset without friction, nor material damping between wheel and rail) is intended to analyze normal contact force calculations and modeling of flanging with impacts. Although one would believe it extremely elementary, it is expected to find different results due to differences in coding assumptions.
All interested parties are invited to participate in this benchmarking exercise and submit results no later than June 16, 2006. All submittals will be published in a joint FRA/DTT report in which all simulation results will compare with one another. The published report will be made available within 60 days of deadline.

LD BENCHMARK INPUT DATA

Wheelset

- **Mass: 1568 kg**
- **Roll inertia: 656 kg.m^2**
- **Pitch inertia[1]: 168 kg.m^2**
- **Rolling Radius: 0.457 m**
- **Wheels load at equilibrium: 90kN (wheelset is loaded with a vertical non inertial constant force of 164.618 kN – gravity: 9.81 m/s/s)**
- **4 DOF: Lateral (Y), Vertical (Z), Roll (Φ), Pitch (Ω)**
- **Wheel Profiles: There are 2 wheel profiles in the non-linear exercises:**
  A. Actual wheel profile 1:40 taper “awprof” (numeric file: “awprof.yz”)
  B. Simplified wheel profiles “swprof” (numeric file: “swprof.yz”)
  The files are provided in mm - See drawings page 5
- **Back to Back spacing: 1.35214 m**

Material Properties

- **Poisson’s ratio = 0.28**
- **Modulus of elasticity 210000.0 N/mm^2**
- **Modulus of rigidity 82000.0 N/mm^2**

Wheel-Rail Friction

- **< 10-7 (as close to zero as possible without causing numerical problems)**

Track

- **Rails Profile: There are 2 rail profiles in the non-linear exercises:**
  A. Actual rail profile “arprof” (numeric file: “arprof.yz”)
  B. Simplified rail profiles “srprof” (numeric file: “srprof.yz”)
  The files are provided in mm - See drawings page 5
  Data in numeric files include 1:40 cant.

[1] Pitch inertia and DOF are only necessary if the code takes gyroscopic effects into account (could be neglected)

- **Gage: 1.4351 m (56.5") measured at 14mm below top of rails**
- **Suspension: rigid (or infinite mass)**

BENCHMARKING EXERCISES

1st CASE : Wheelset is free with an initial lateral velocity

	Exercise 1	Exercise 2	Exercise 3	Exercise 4
Initial Conditions				
X	0	0	0	0
Y	0	0	0	0
Z	0	0	0	0
Pitch Ω	0	0	0	0
Roll Φ	0	0	0	0
dX/dt	1 m/s (constant)	1 m/s (constant)	1 m/s (constant)	1 m/s (constant)
dY/dt	0.1 m/s	0.5 m/s	1 m/s	2 m/s
dZ/dt	0	0	0	0
dΩ/dt	2.19 rad/s	2.19 rad/s	2.19 rad/s	2.19 rad/s
dΦ/dt	3.33 mrad/s	16.67 mrad/s	33.3 mrad/s	66.7 mrad/s
Constrained Degrees of Freedom				
Yaw	0 rad	0 rad	0 rad	0 rad

Note: roll velocity can also be internally linked to the imposed lateral velocity if the code uses rigid constraints.

In the 1st CASE, all participants are requested to carry out the 4 exercises twice: first using the data given above with a wheelset and rails having the actual wheel and rail profiles (awprof and arprof), and second using the data given above with a wheelset and rails having the simplified wheel and rail profiles (swprof and srprof).

Note: given the convention of Y positive to the left, the imposed lateral velocity will generate flange contact on the left wheel first. The simulation time for each exercise should be chosen such that the following sequence occurs: flange contact on the left wheel, flange contact on the right wheel, and the wheelset returns to center.

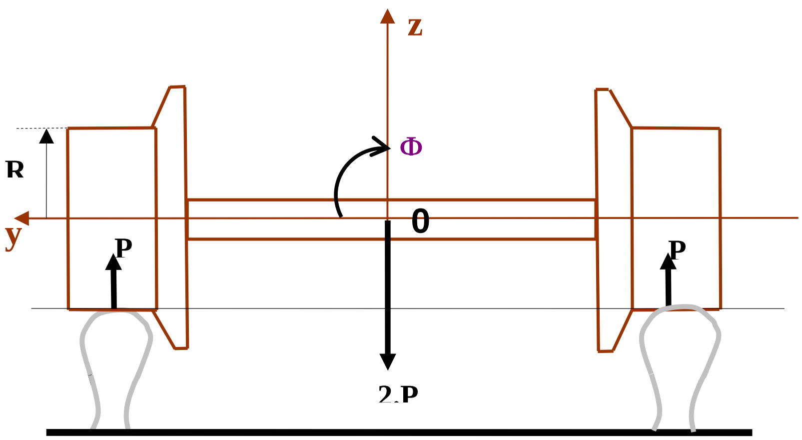
2nd CASE : Initial conditions: given in table below – a slowly growing lateral force (5.E3N/s) is applied at the wheelset CG up to derailment

	Exercise 5
Initial Conditions	
X	0
Y	0
Z	0
Pitch Ω	0
Roll Φ	0
dX/dt	1 m/s (constant)
dY/dt	0
dZ/dt	0

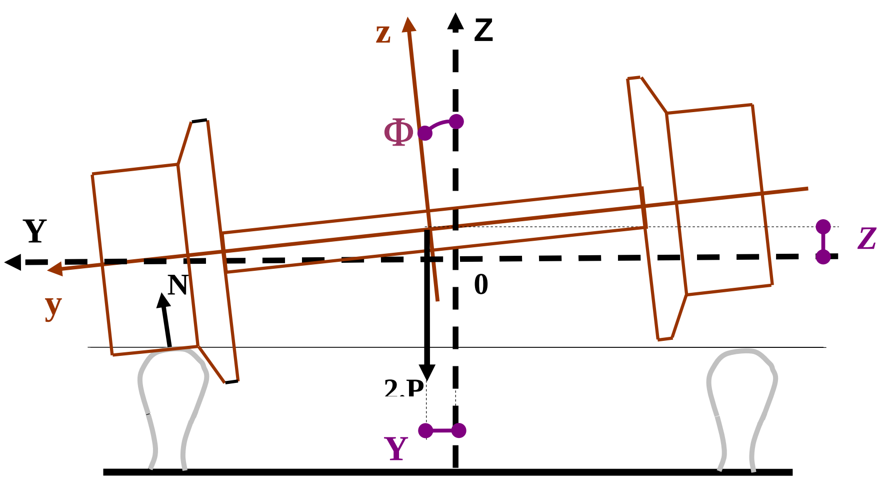
dΩ/dt	**2.19 rad/s**
dΦ/dt	**0**
Constrained Degrees of Freedom	
Yaw	**0 rad**

In the 2nd CASE, all participants are requested to carry out the exercise 5 twice: first using the data given above with a wheelset and rails having the actual wheel and rail profiles (awprof and arprof), and second using the data given above with a wheelset and rails having the simplified wheel and rail profiles (swprof and srprof).

Note: the external force applied at the CG should be oriented in the lateral direction defined by the track coordinate system. As the wheelset moves to the left, the wheelset will roll and the wheelset coordinate system will no longer coincide with the track coordinate system as shown in the figures below. The simulation time for each exercise should be sufficient to allow for wheelset derailment.



Coordinate System Convention



Typical Wheelset Roll Relative to Track [Y, Z, Φ]

SIMULATIONS AND REPORTING OF RESULTS

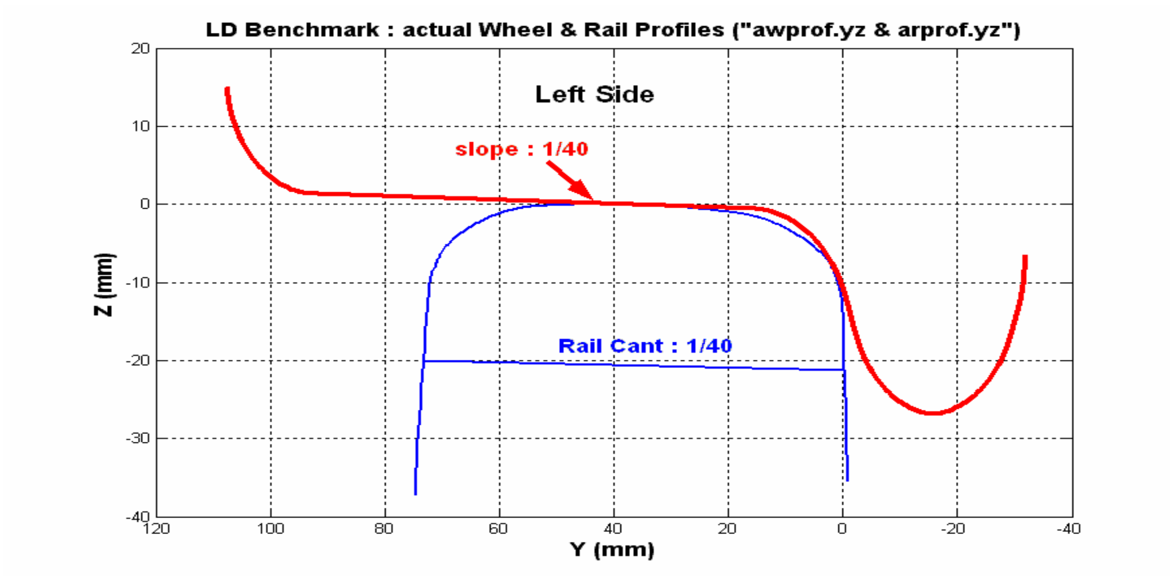
Frame: Y positive to the left, Z positive upwards
Plots as functions of time in track frame:

- **Wheelset Lateral Displacement Y**
- **Wheelset Vertical Displacement Z**
- **Wheelset Roll Displacement Φ**
- **Wheelset Lateral Velocity**
- **Wheelset Vertical Velocity**
- **Wheelset Roll Velocity**
- **Wheelset Lateral Acceleration**
- **Wheelset Vertical Acceleration**
- **Wheelset Roll Acceleration**
- **Contact angles on tread and flange of both left and right wheels**
- **Normal forces on tread and flange of both left and right wheels**
- **Vertical forces on tread and flange of both left and right wheels**
- **Lateral forces on tread and flange of both left and right wheels**
- **Position of every contact point (lateral and vertical location)**
- **Rolling radius at every contact point**
- **Energy balance (kinetic and potential energy components)**

Numerical files of profiles are available at the VOLPE Center Site:
ftp://ftp.volpe.dot.gov/pub/dts76/marquis/ldbenchmark/

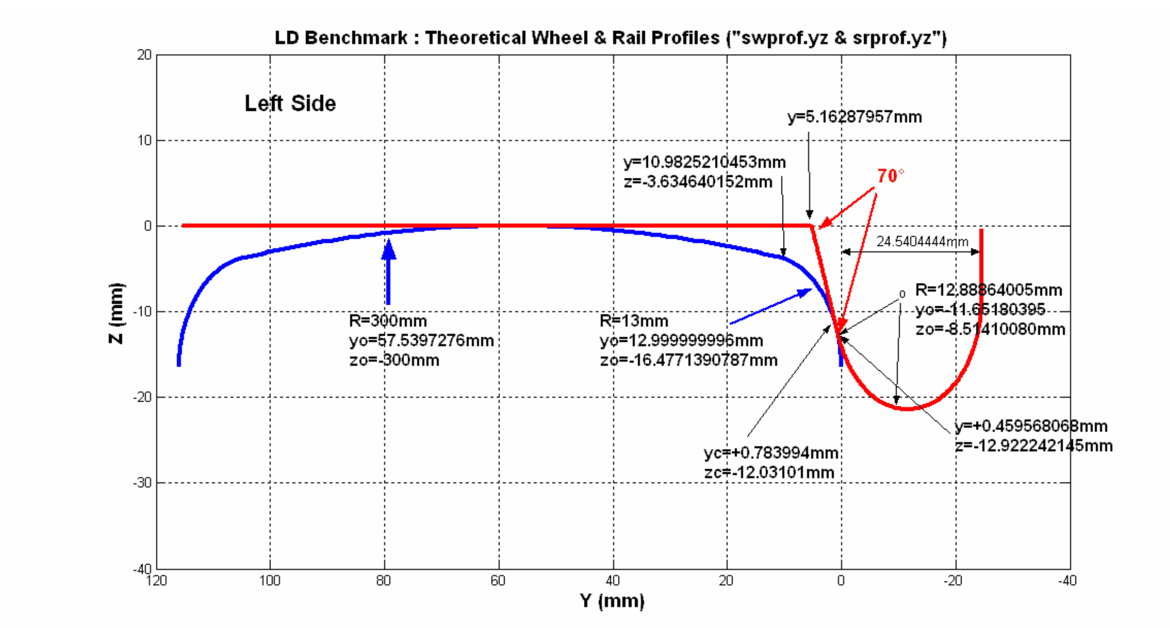
Simulation results should be sent either to Brian Marquis or to Jean-Pierre Pascal:
Brian.Marquis@volpe.dot.gov
pascal.voc@wanadoo.fr
who will publish the responses on the Volpe Center site in June 2006. Requested results should be submitted in 2 file formats. The first group of files should be an ASCII file for each simulation containing time histories results in labeled columns (5 exercises x 2 wheel/rail combinations = 10 ASCII files total). The output frequency should be sufficient to accurately capture all dynamic behavior. The second file should be a pdf file containing plots of each result. This will provide a means of verifying our understanding of the ASCII files. Along with the results, the organizers request each participant submit a brief abstract (maximum 4 pages) describing the program used and details of the wheel/rail contact force algorithm.

Wheel and Rail Profiles



Actual Wheel and Rail Profiles (numeric files)

note: in the numeric file, wheel back is at y=0 (shifted in the drawing)
and rail gage point is also at y=0 (not shifted)
Using benchmark data, rigid axle clearance results at 2x10.18mm



Theoretical Wheel and Rail Profiles (also in numeric files)

note: in the numeric file, wheel back is at y=0 (shifted by 24.54mm in the drawing)
and rail vertical is at y=0 (not shifted)
Using benchmark data, rigid axle clearance results at 2x16.94mm