WHEEL / RAIL NOISE, CORRUGATION and REPROFILING

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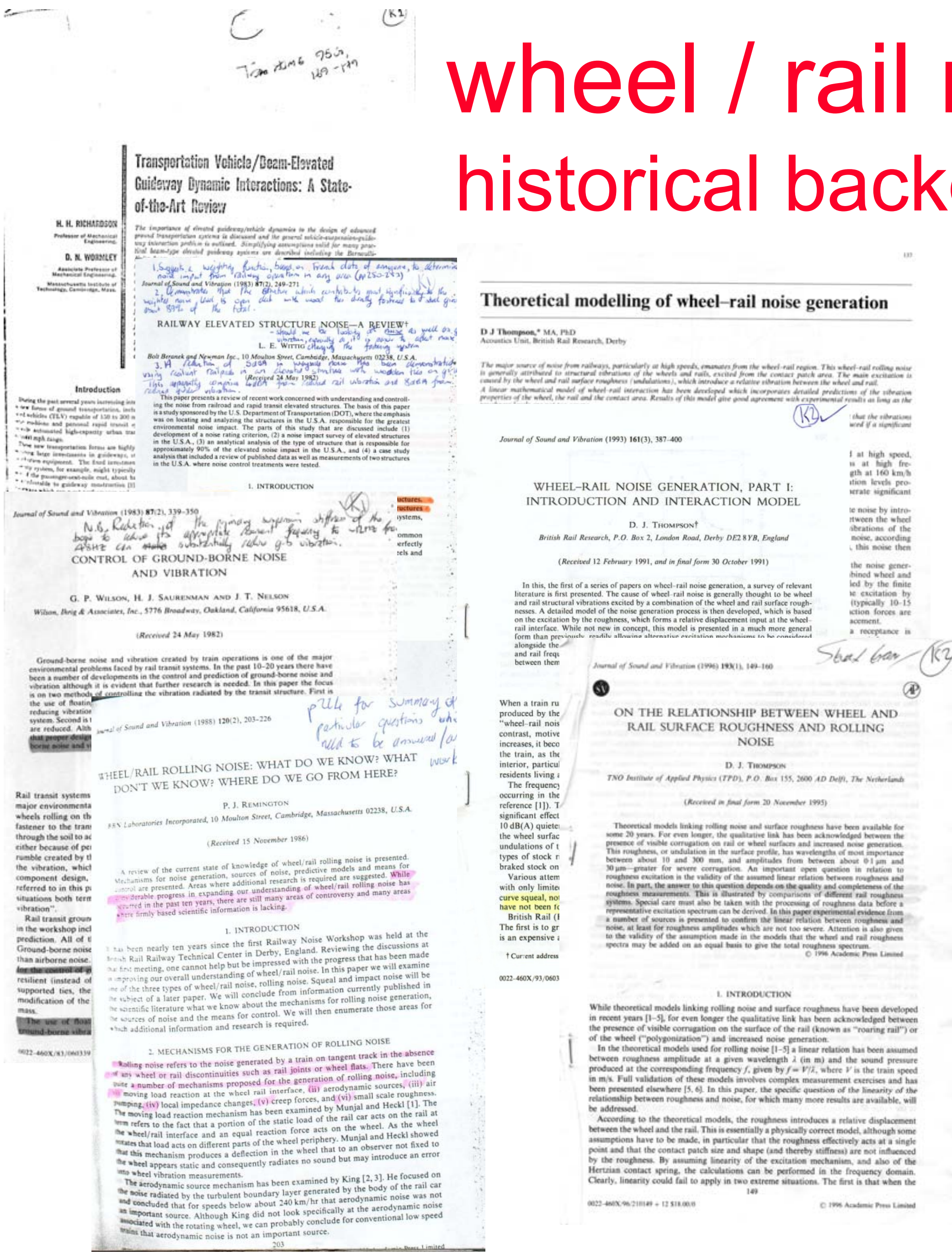
scope of presentation

- Wheel/rail noise
  - historical background
  - types of wheel/rail noise
  - wheel and rail irregularities and noise
- reprofiling and corrugation development
  - good and bad practice
- Standards to control irregularities
- Measurements
  - corrugation, acoustic roughness and long waves (rails)
  - OOR, corrugation, acoustic roughness,.. (wheels)
- conclusions



wheel / rail noise:
historical background

- 1970s-1980s
  - much work done in North America
  - structure-borne noise was of particular interest
- 1990s to present
  - more work in Europe, less in US
  - standards drafted mainly in Europe
- future
  - China
  - resurgence of interest in US?

sources of wheel / rail noise

- Bender, Remington, Galaitsis, Rudd, Ver (BBN, 1976)

  1. rolling noise:
     – wheel and rail “roughness” critical
  2. impact:
     – wheel / rail discontinuities
     – could consider as special case of 1.
  3. squeal:
     – stick/slip: difference in static / dynamic friction critical
     – “tonal” response: excitation of lightly-damped wheel resonances
     – “friction modifier” is an excellent practical control
     – can affect slightly by grinding to improve steering, and thereby reduce “angle of attack”

  Here we discuss noise excited by wheel & rail irregularities.

Wavelength ranges of interest

		20m/s (72km/h)	50m/s (180km/h)
audible ground-borne noise	**25-250Hz**	800-80mm	2000-200mm
structure-borne noise	**100-2000Hz**	200-10mm	500-25mm
wheel-rail rolling noise	**100-5000Hz**	200-4mm	500-10mm

- large range of wavelengths of interest
  - at least 4-500mm just for rolling noise at typical train speeds
  - 4-2000mm for rolling noise and ground-borne noise

model of wheel / rail *rolling* noise generation (DJT, 1991)

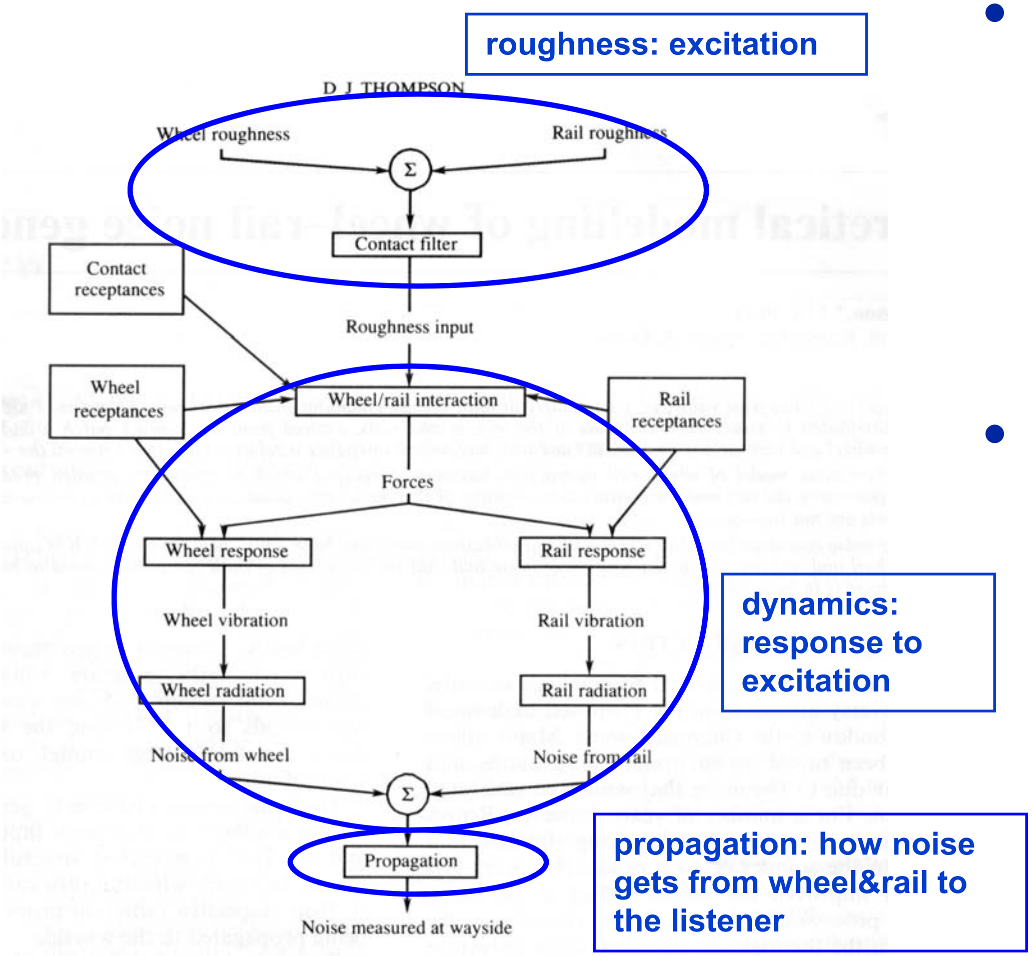
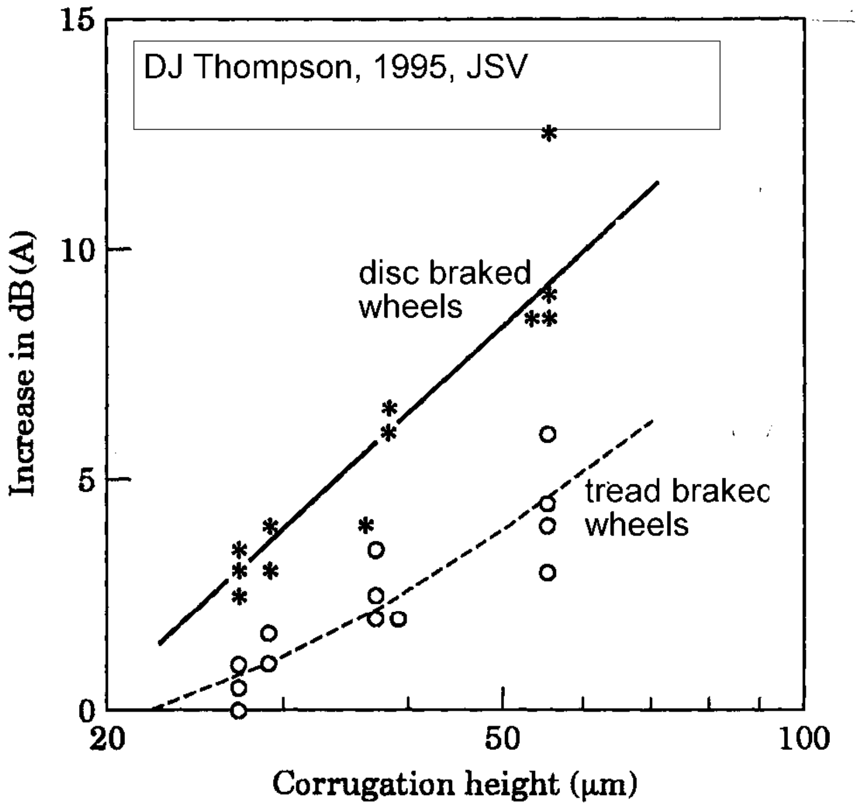


Fig. 1 A framework for wheel–rail noise generation

- excitation of dynamic behaviour by wheel/rail “roughness” i.e. irregularities
- control noise by
  - controlling roughness
  - modifying dynamic behaviour
  - affecting propagation

Model of Remington (1988) is similar

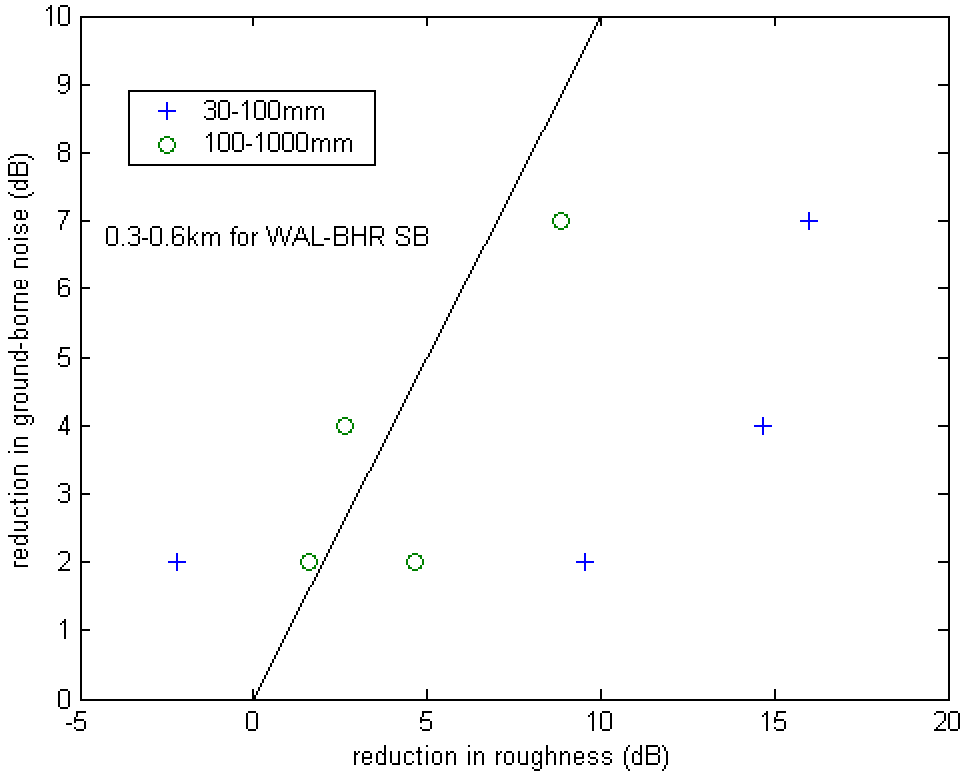
How much do irregularities influence air-borne noise?



- >10dB increase in noise with corrugation ("short" wavelength)

∴ removal of irregularities can reduce noise by >10dB

How much do irregularities influence ground-borne noise?



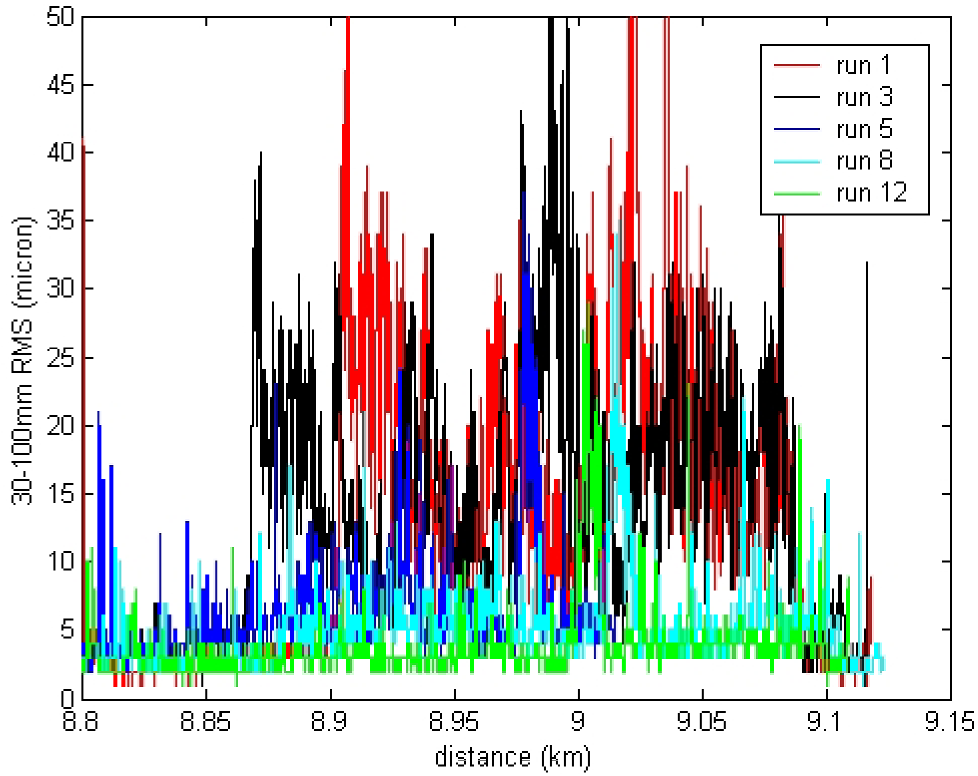
- noise data from 4 sites courtesy of James Shepherd, N&V Engineer, London Underground
- corrugation pre/post grinding from Schweerbau GmbH (CAT)

- in-property noise reduction correlates roughly with reduction in “roughness” in 100-1000mm wavelength range
  - 20-200Hz for 20m/s (50mph)
  - 25-250Hz considered the range for “audible ground-borne noise”
- expect in-vehicle / air-borne noise to correlate better with short wavelength roughness
  - reduction in 30-100mm roughness with grinding is much greater than the reduction in 100-1000mm roughness

rail corrugation and wheel / rail noise: the influence of reprofiling

- rail corrugation is the main cause of excitation of wheel and rail, and therefore of noise
- removal (or prevention) of corrugation is therefore a critically important way of reducing wheel / rail noise
  - prevention:
    - asymmetric profiling to improve curving and reduce corrugation in curves
    - reduce irregularities: “prevention” where discrete irregularities e.g. welds are critical in corrugation initiation
  - reprofiling (mainly grinding) is otherwise a “treatment” of corrugation, albeit one of the most widely used and most effective

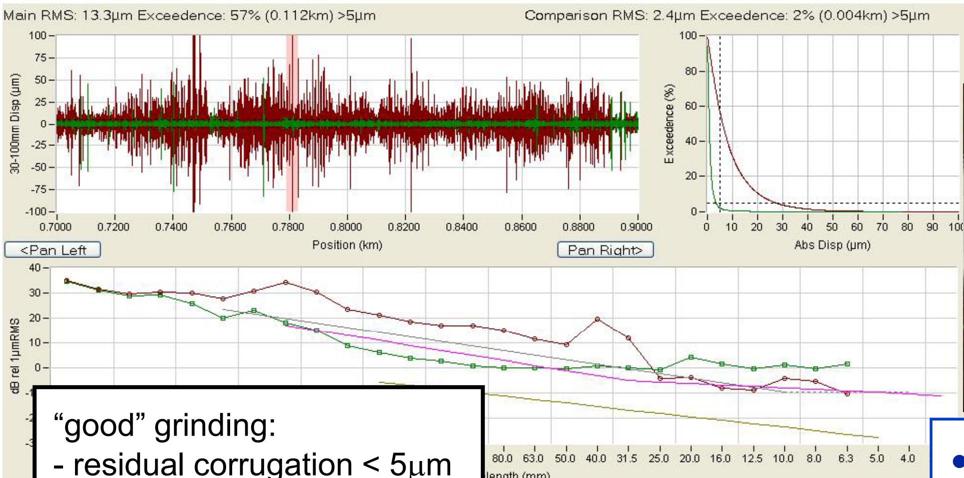
removal of corrugation
(metro system)



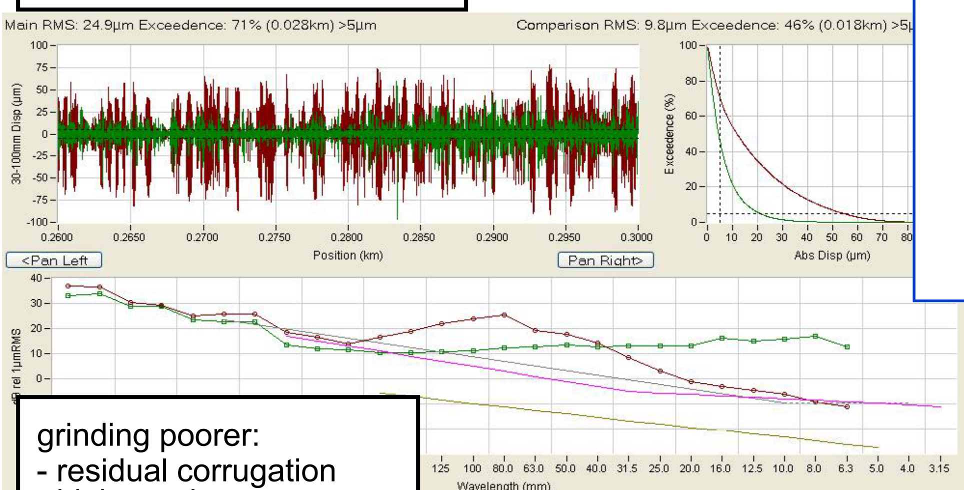
- reduction in 30-100mm corrugation: 12 passes
  - > 0.050mm RMS initially
  - < 0.003mm (0.12 thou) RMS after 12 passes
- measurements (at 1mm interval) *during grinding* using train-based equipment
  - accuracy of microns

reprofiling

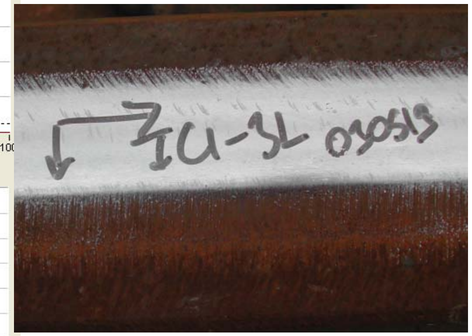
what is possible and what should be avoided?



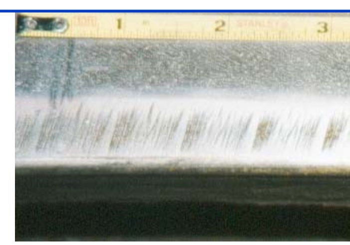
"good" grinding:
- residual corrugation < 5µm
- spectrum below ISO3095



grinding poorer:
- residual corrugation
- high roughness
- spectrum well above ISO3095

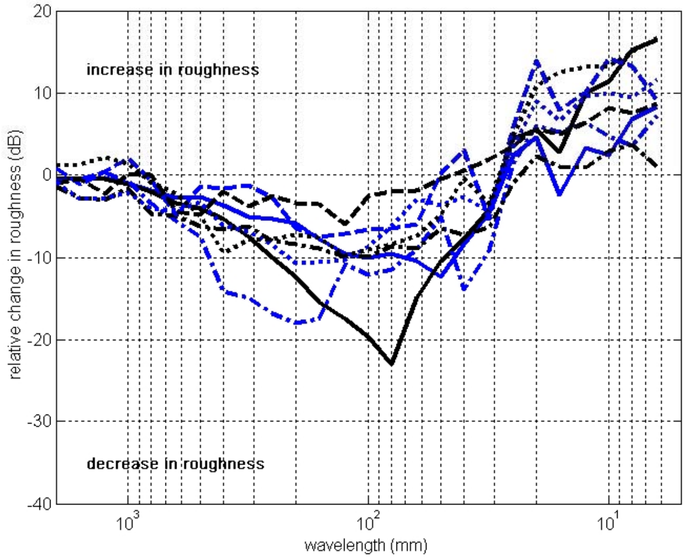


- minimise
  - "grinding signature" (typically 20-30mm wavelength)
  - short wave roughness

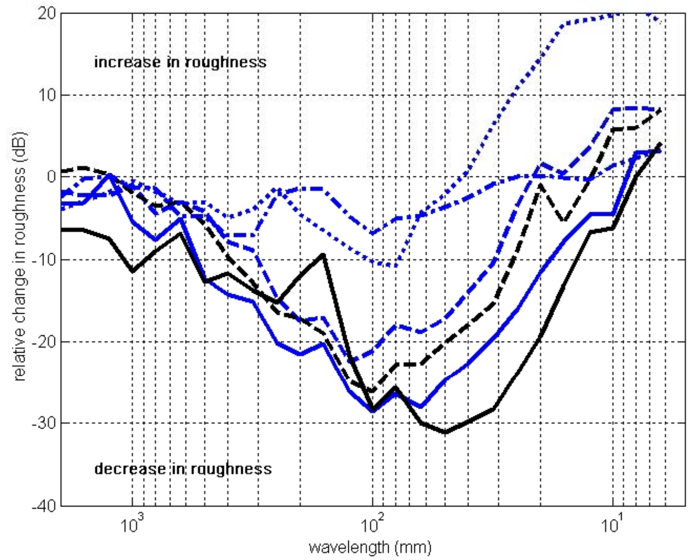


Effect of reprofiling on irregularities

typical

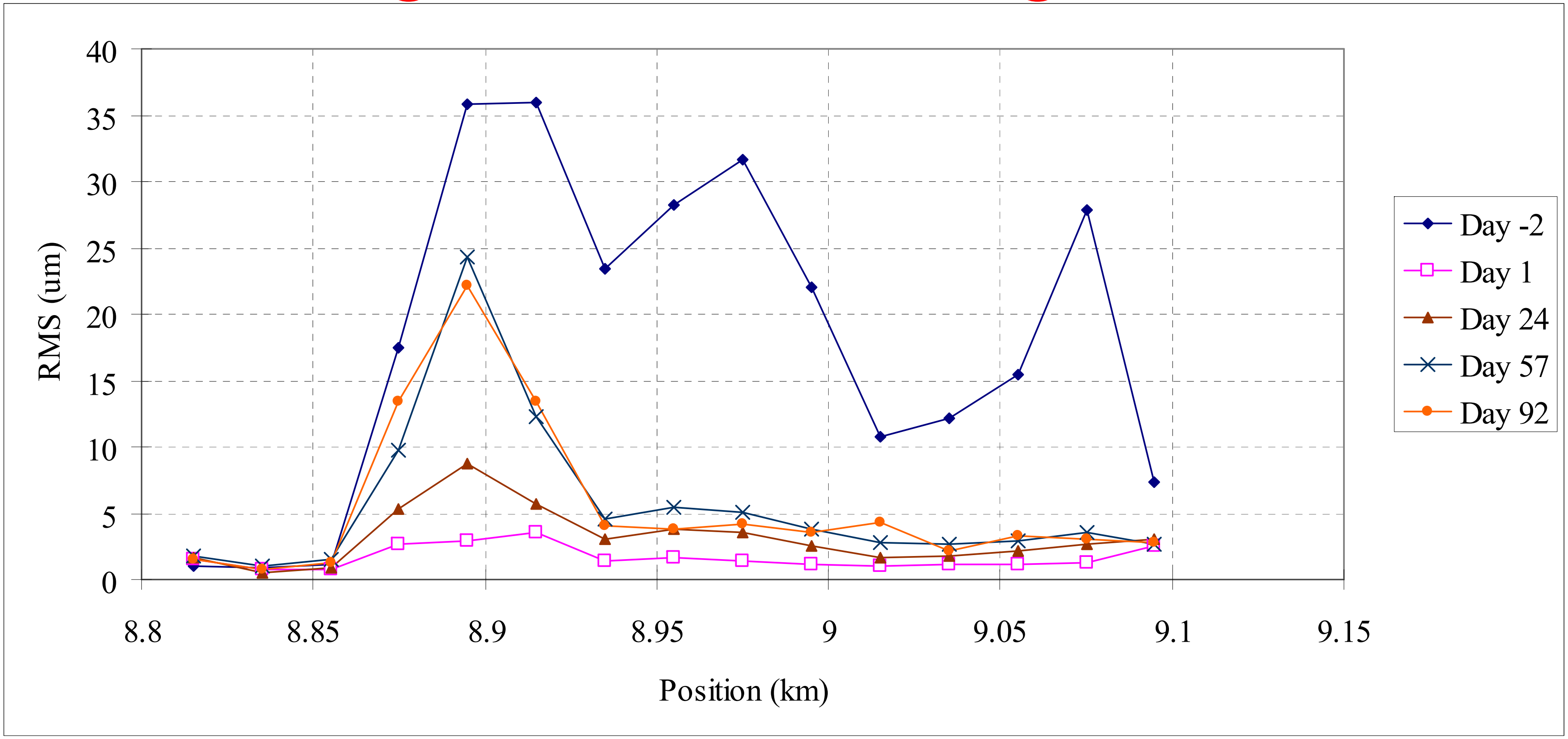


extremes



- Typical reduction in roughness of 10-20dB in mid-wavelength range (30-300mm).
- <u>Increase</u> in roughness for λ<30mm

regrowth of corrugation



- 30-100mm corrugation on metro (measured with CAT)
  – well developed after only 2 months
- note that corrugation develops rapidly from very small residual corrugation (<4μm RMS)

NB This is not typical: very rapid development

EN / ISO standards relevant to reprofiling and irregularities

- EN ISO 3095
  - acoustic type testing of vehicles
- EN 15610: 2009
  - rail roughness measurement
    - now contains the specification for rail roughness measurement that was once in EN ISO 3095
    - forms basis of EN for wheel roughness measurement
- EN 13231-3:2006
  - reprofiling of rails
  - also 2012 version for those with lower standards
- EN 13674-1
  - rail standard

Wavelength ranges considered in Standards

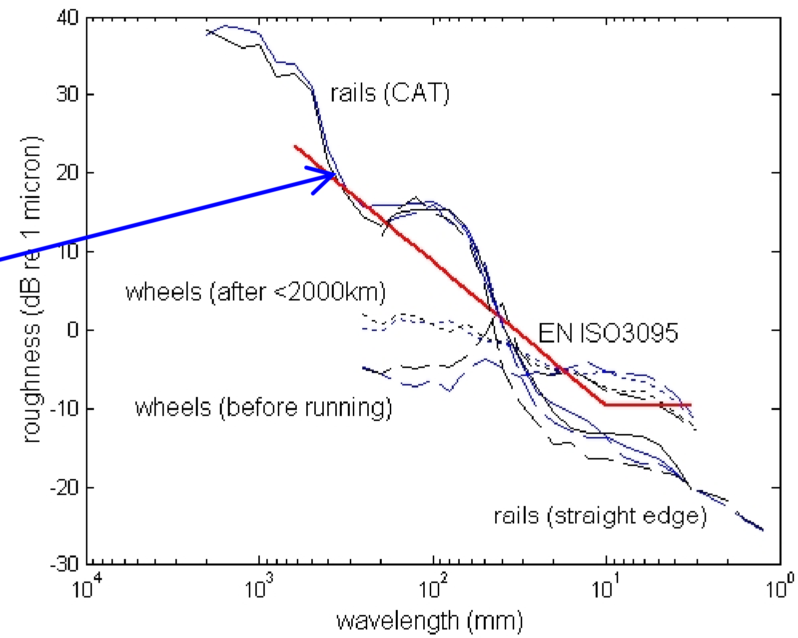
(European and International)

	maximum (mm)	**minimum (mm)**
EN 15610	250	3.15
EN ISO 3095	630	3.15
EN 13231-3	1000	10

- EN15610 is adequate for w/r rolling noise for low speed traffic (< 20 m/s)
- EN 3095 is adequate for w/r rolling noise for higher speeds (< 50m/s)
- Only EN 13231-3 approaches sufficiency for ground-borne noise
  - but it is not an acoustic standard

EN ISO 3095:2005 & EN 15610:2009

- EN ISO 3095: acoustic type testing of vehicles
  - specifies the limiting roughness spectrum for a site to be used for this purpose
  - strictly not a standard for “allowable corrugation”, but is nevertheless useful
    - more demanding than EN13231-3:2006
  - similar (lower) levels specified for TSIs in Europe (rules for interworking of trains)



- EN 15610 has the same roughness limit

EN 13231-3:2006

- European standard for reprofiling of rails

Table 1 — Window lengths

Wavelength range (mm)	10 - 30	30 - 100	100 - 300	300 - 1 000
Window length (m)	0,15	0,5	1,5	5

Table 2 — Moving average of RMS amplitude limits

Wavelength range (mm)	10 - 30	30 - 100	100 - 300	300 - 1 000
Limit of moving average of RMS amplitude (mm)	0,004	0,004	0,012	0,040

Table 3 — Moving average of peak-to-peak amplitude limits

Wavelength range (mm)	10 - 30	30 - 100	100 - 300	300 - 1 000
Limit of moving average of peak-to-peak amplitude (mm)	0,010	0,010	0,030	0,100

Table 4 — Acceptance criteria for longitudinal profile expressed in terms of allowable percentages of track exceeding moving average RMS or peak-to-peak amplitude limits

Wavelength range (mm)	10 - 30	30 - 100	100 - 300	300 - 1 000
Class 1	5 %	5 %	5 %	10 %
Class 2	No requirement	10 %	10 %	No requirement

most significant wavelength ranges

- EN 13231-3:2012 has more generous limits for allowable residual irregularities

EN 13674-1:2003

- European rail standard
  - vertical flatness of new rails
    - Class A

      ≤0.3mm over 3m chord

      ≤0.2mm over 1m chord
    - Class B

      ≤0.4mm over 3m chord

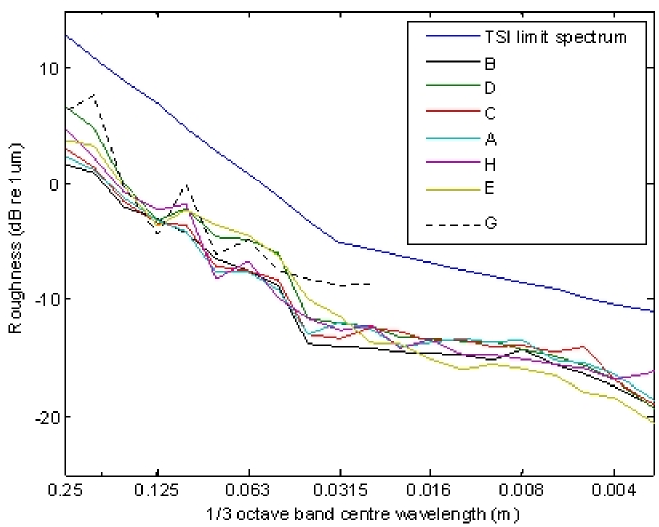
      ≤0.3mm over 1m chord

    At least 95% of rails to be within limits specified

    Remainder to be within 0.1mm of these limits.

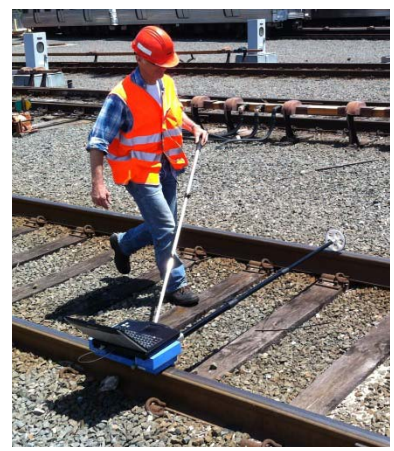
These limits are primarily a means of reducing relatively low frequency (<50Hz) dynamic forces (vehicle ride, GBV, ballast degradation)

measurement of roughness & corrugation:
manual equipment



results from CEN test of EN15610: CAT is “H”

- straight-edge based equipment
  - simple
  - slow, bulky, limited measuring length (1m increments)
- trolley (CAT)
  - accuracy better than 1μm
  - useable by one person
  - measure at walking speed (1m/s)
  - can also measure long wavelengths (>1m) and welds



vehicle-based equipment

- systems for
  - rail grinders / reprofiling trains
  - hi-rail or similar
  - self-contained trolleys
- measure microns at up to 50km/h

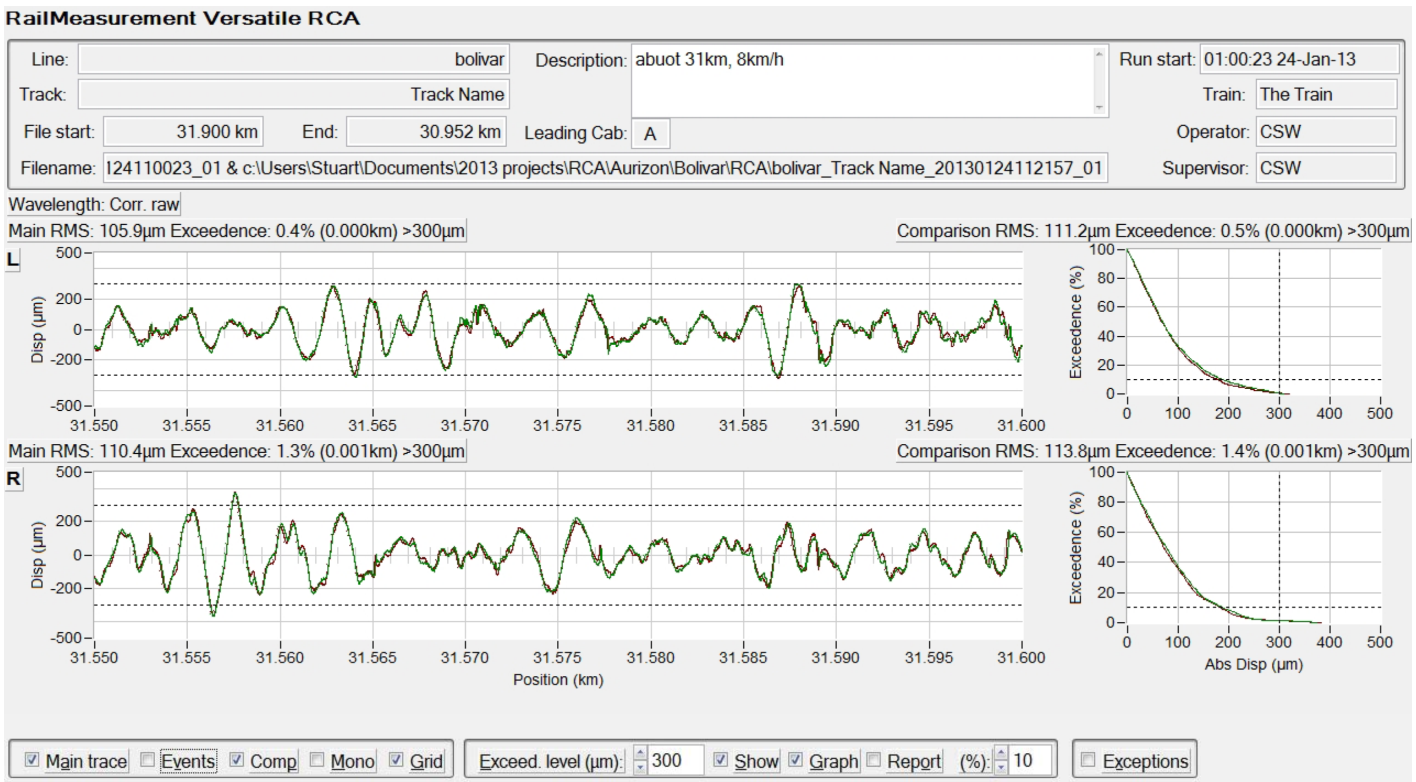
How good is an instrument?

- Can an instrument be “calibrated” or even “validated” for measurements of long wavelength?
- If not, how can we tell whether or not an instrument is “correct”?
- Can we tell how correct it is?

proposal

If repeatability is better, then equipment is better.

an objective and relevant assessment of "repeatability"



- Two measurements with RCA under same conditions over 50m of track.
  - raw displacement "looks" repeatable

Objective assessment of repeatability

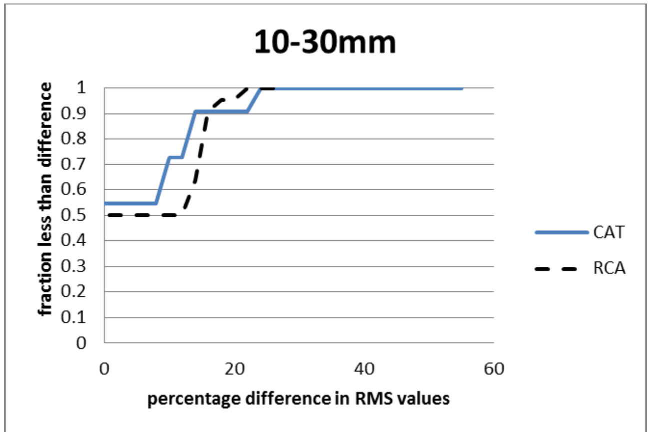
- Percentage difference in measurements

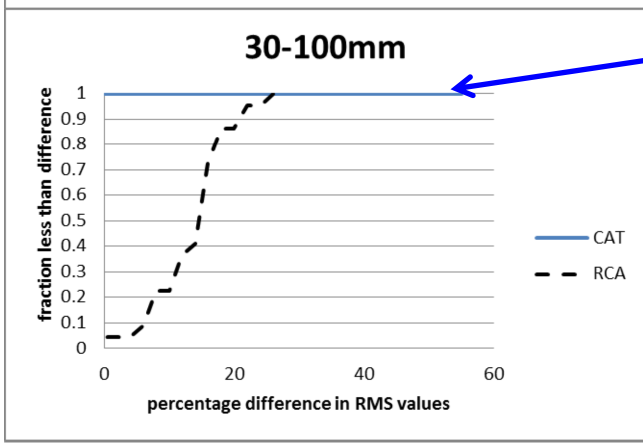
$$y = 2 * |s_A - s_B| * 100 / (s_A + s_B) \%$$

where s_A and s_B are RMS amplitudes of irregularities for runs A and B, which are made under <u>identical</u> conditions e.g. speed, direction,….

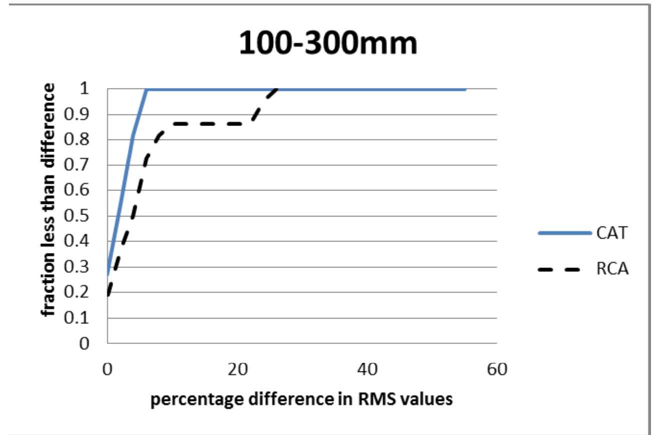
- calculate y for
  - same section of track (10m lengths)
  - different wavelength ranges (10-30mm, 30-100mm,….,1000-3000mm)
- express as fractional exceedences

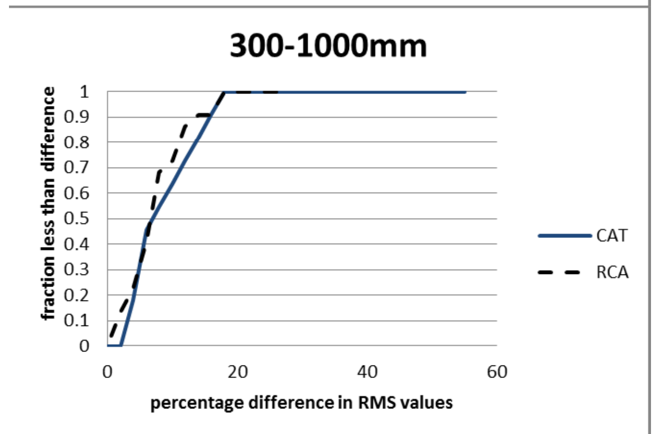
fractional exceedences

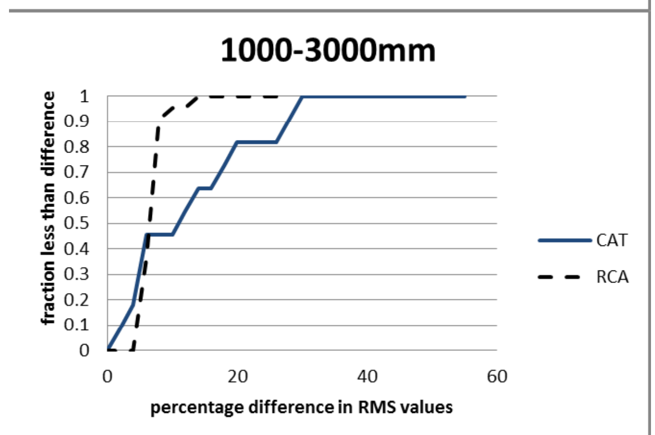




perfect repeat-ability of CAT in 30-100mm band

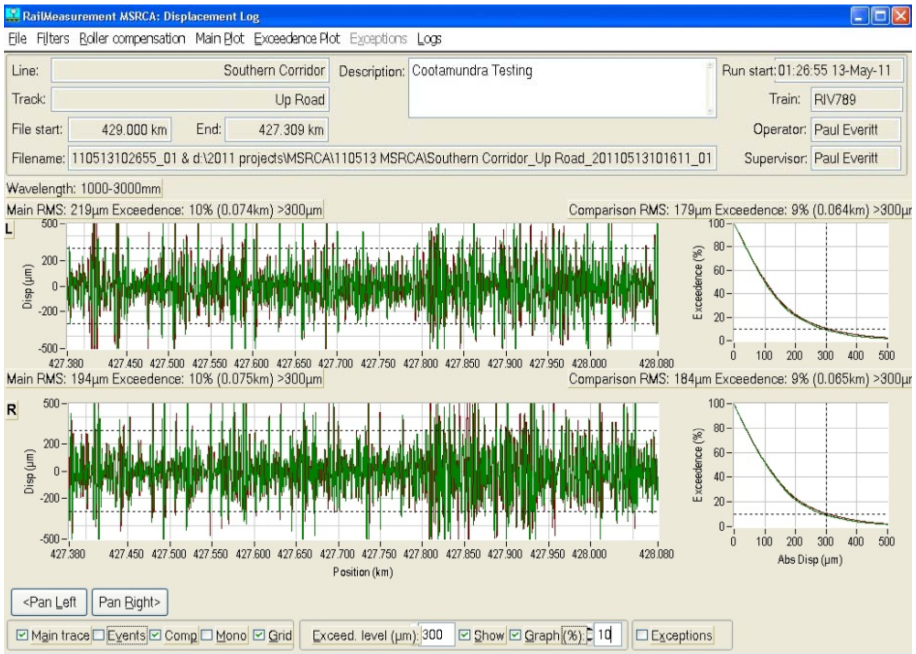


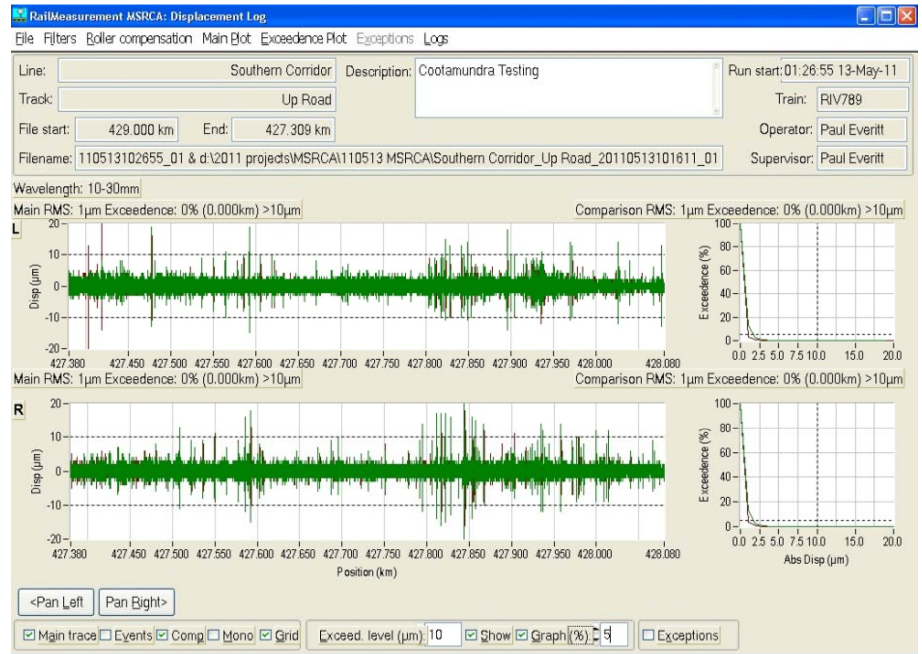




- perfect repeatability corresponds to exceedence of 1.0 for difference of 0% in RMS values

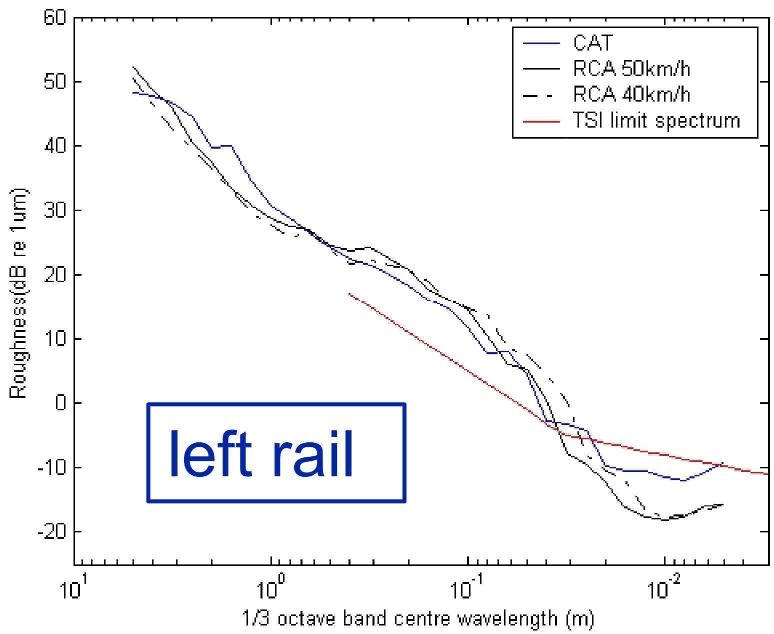
effect of speed on reproducibility

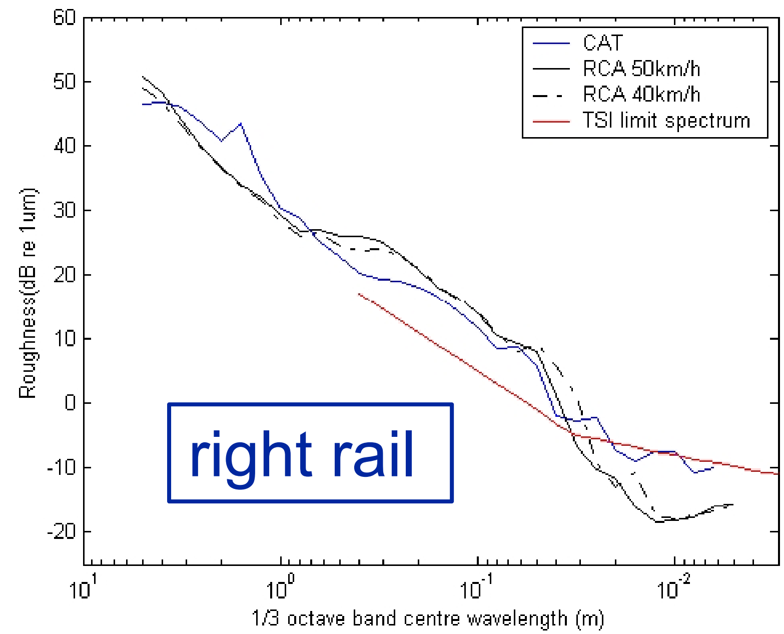




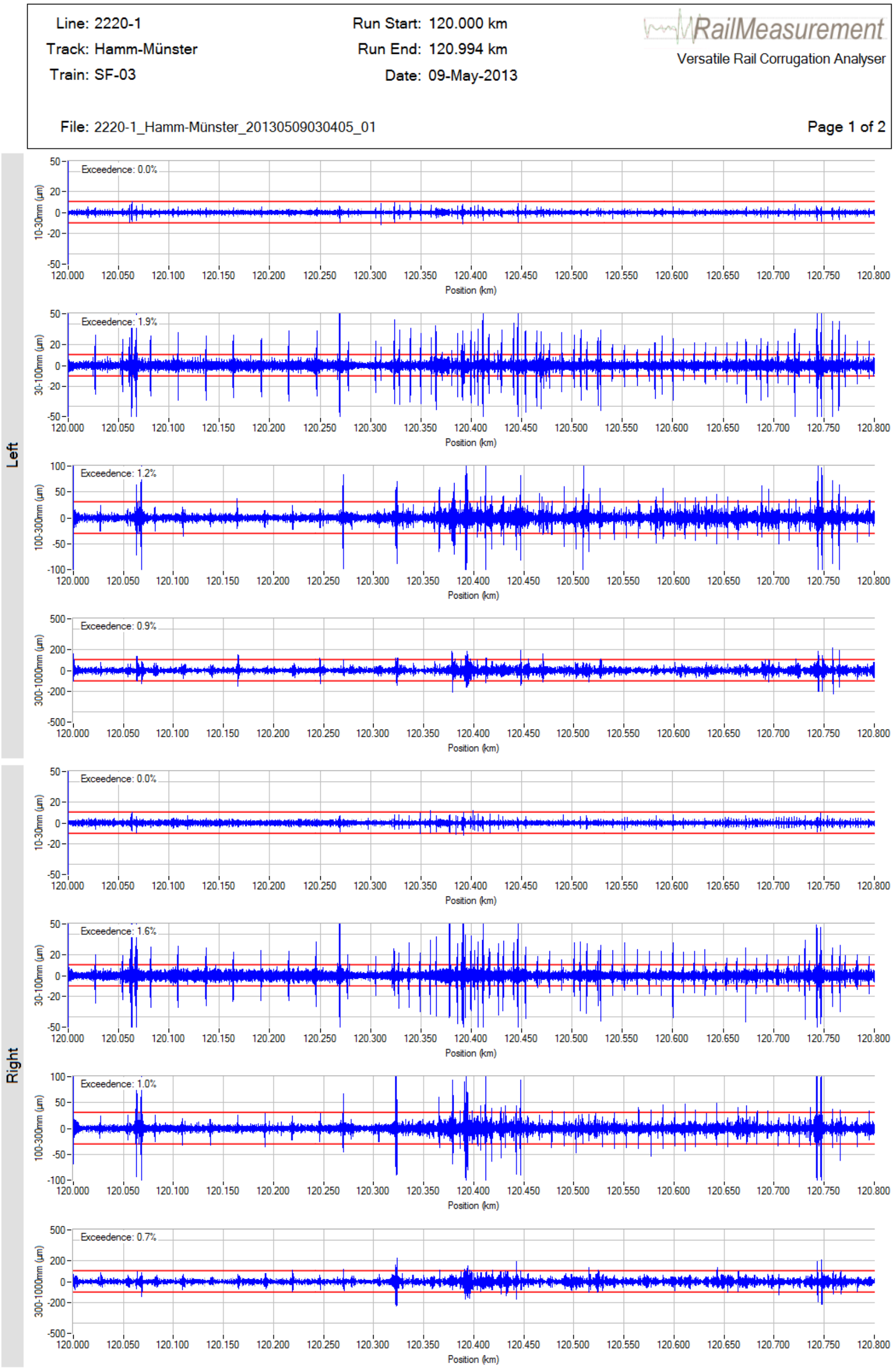
- Measurements at 40km/h and 50km/h over 700m
  - 1000-3000mm (left), full scale +/-0.500mm
  - 10-30mm (right), full scale +/-0.020mm
- can develop objective measures of repeatability and reproducibility

one-third octave spectra (6-5000mm)





- excellent reproducibility of RCA
- good correlation with CAT for λ>20mm
  - short waves slightly underestimated by RCA contact



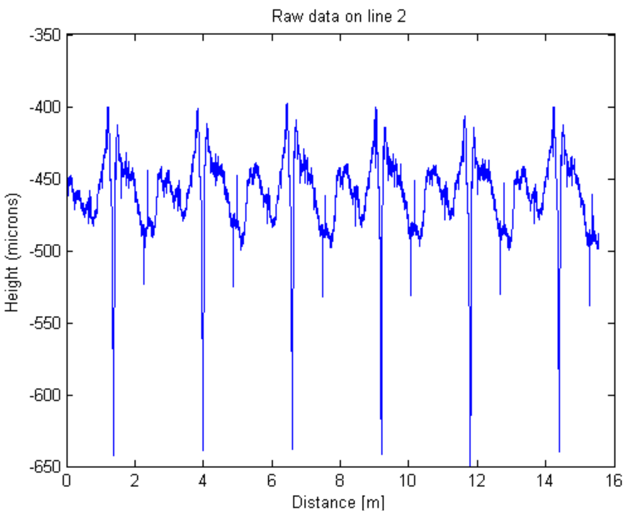
presentationof corrugation data

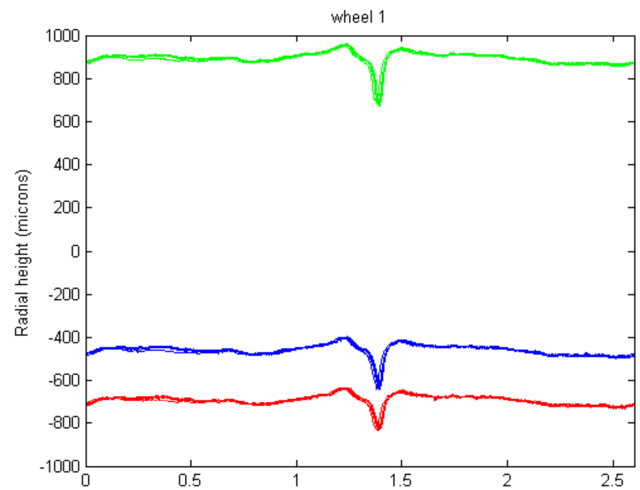
- 4 wavelength ranges, both rails, 500m per page
- percentages noted out of prescribed limits

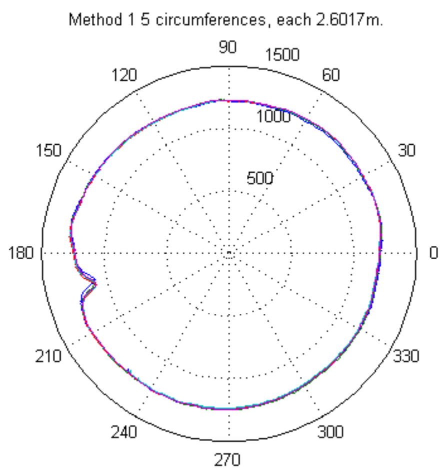
Wheel irregularities

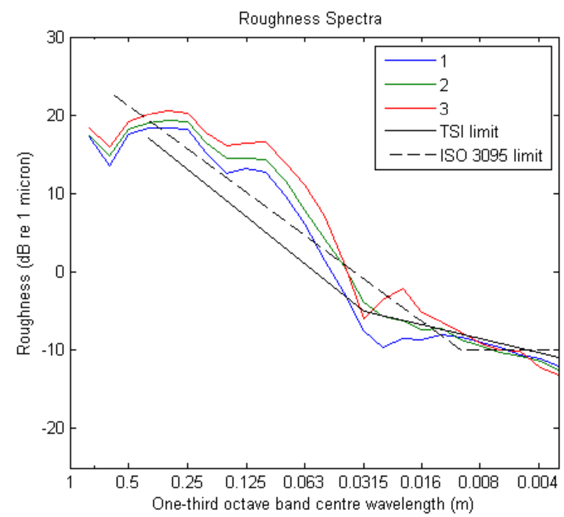
- measurements using RML "TriTops" instrument
  - developed in collaboration with ISVR
  - measures OOR, roughness, general irregularities (flats etc), diameter

wheelflat



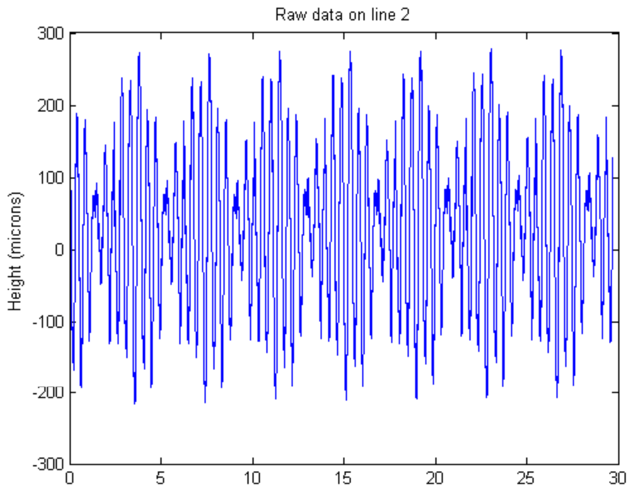


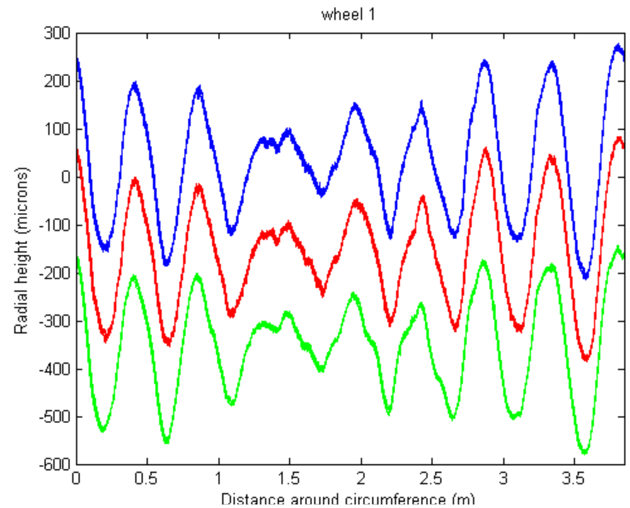


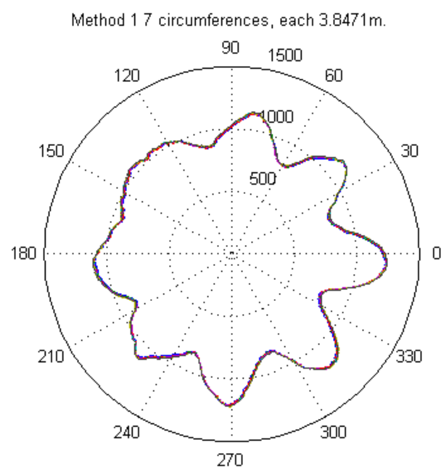


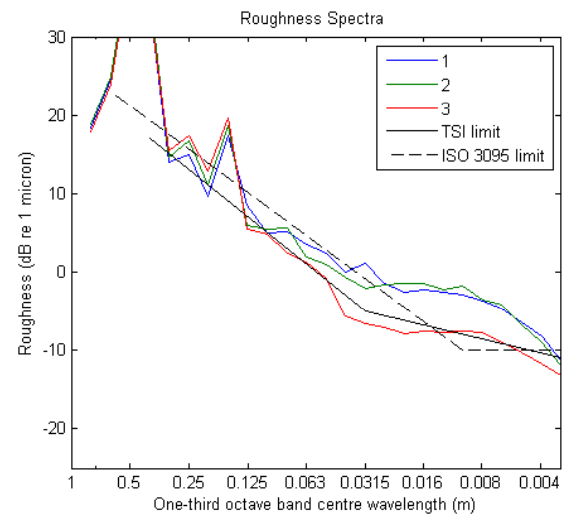
- analyses of interest for both acoustics and maintenance

periodic out-of-round (OOR)









- very graphic demonstration of OOR

conclusions (1 of 2)

- hand-held and vehicle-based equipment is available that is sufficiently accurate to measure irregularities that are important for corrugation and reprofiling
  - suitable for wavelengths of at least 10-5000mm
- equipment is also available to measure wheel irregularities
- the level of acoustic roughness on worn wheels is similar to that on worn rails
- the wavelength range considered in Standards is barely sufficient for the full range of wheel/rail noise

conclusions (2 of 2)

- short wavelength irregularities influence air-borne noise, long wavelength irregularities influence ground-borne noise e.g. for 50m/s
  - 10-500mm: rolling noise
  - 200-2000Hz: audible ground-borne noise
- reprofiling (grinding and milling) typically
  - reduces irregularities 30-1000mm, primarily 30-300mm
  - increases roughness λ<30mm
  - has little effect on irregularities λ>1m