

RAIL CORRUGATION AND ROLLING NOISE

**specifications, measurements and
long term data**

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scope of presentation

- Wheel/rail rolling noise
 - wheel and rail irregularities and noise
- Rail corrugation
 - huge contribution to rolling noise, “roaring rails”
 - “wavelength fixing mechanisms” relevant to noise
- Specification and control of rail irregularities
 - standards: EN13231-3, EN15610, EN ISO3095
 - implementation
 - measurements
 - post-reprofiling and difference pre to post reprofiling
 - train-borne during grinding
- “long-term” measurements
 - corrugation and noise
- conclusions and recommendations

note

- Introductory work was given in presentation last year to TRB conference
- This presentation follows from last year; it gives
 - practical recommendations
 - results from different railway systems (corrugation and noise)
 - conclusions and recommendations

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

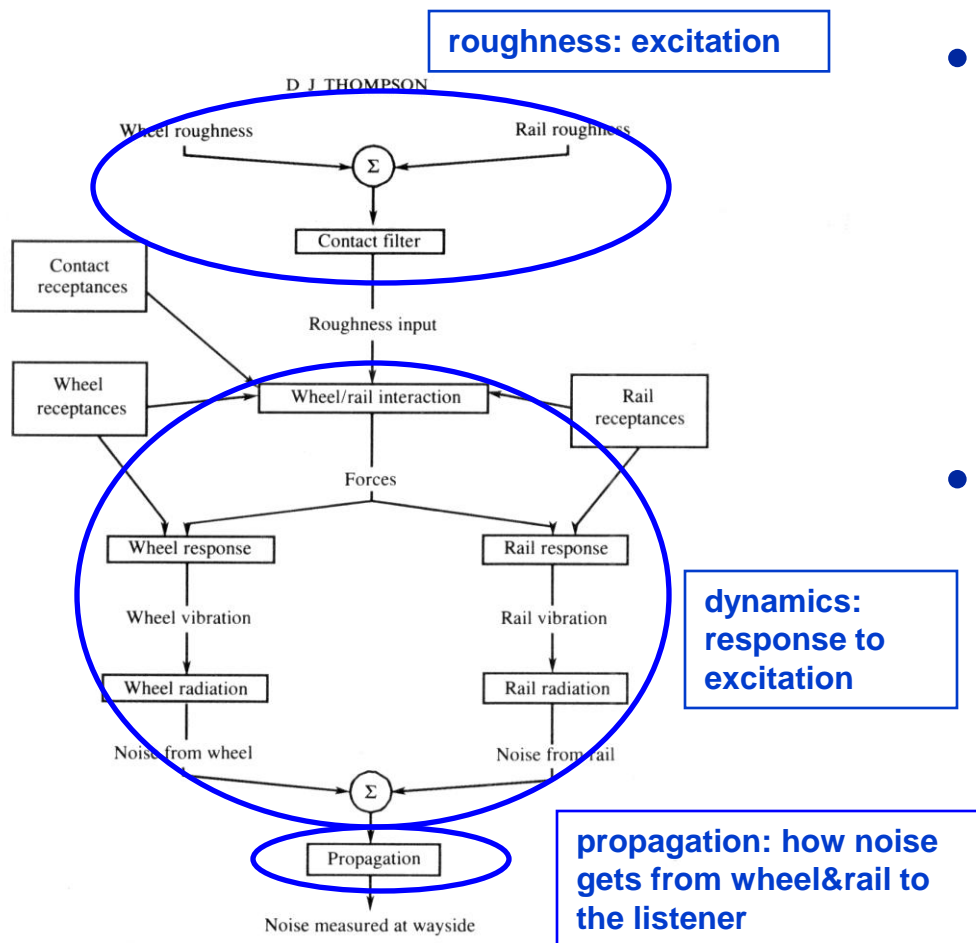
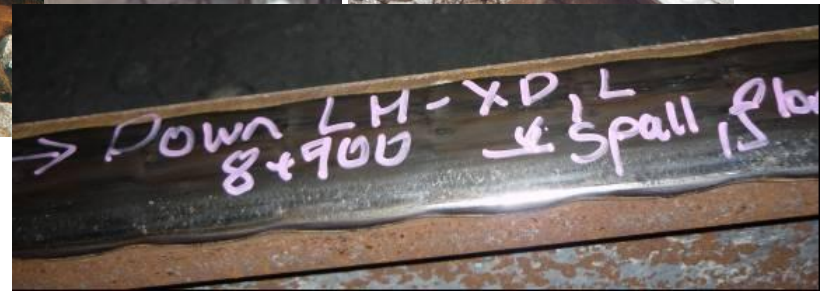
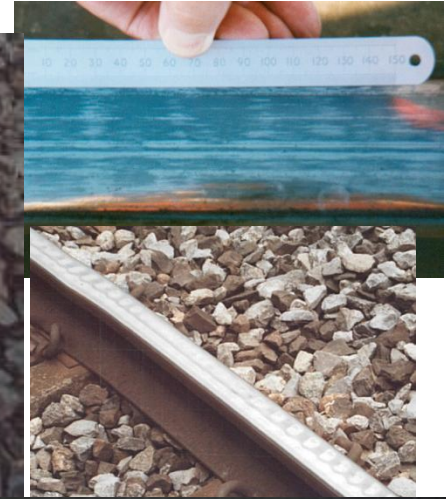
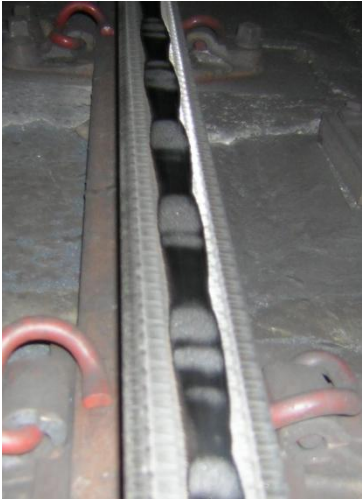


Fig. 1 A framework for wheel-rail noise generation

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

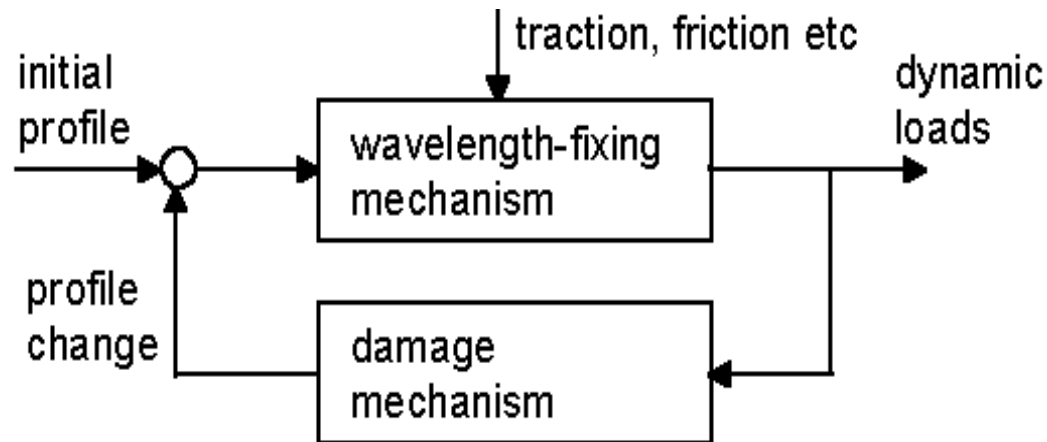
Model of Remington (1988) is similar

rail irregularities: corrugation (quasi-periodic irregularity on the rail)



- there is a great variety of rail corrugation
- corrugation can occur on all types of track

“mechanism” causing rail corrugation



- general mechanism proposed in 1993 (and in different forms previously) is still valid

Refs: SL Grassie and J Kalousek, “Rail corrugation: characteristics, causes and treatments”, *Journal of Rail and Rapid Transit, Procs of I mech E*, 1993, 207F, 57-68

SL Grassie, “Rail corrugation: characteristics, causes and treatments”, *Journal of Rail and Rapid Transit, Procs of I mech E*, 2009, 223F, 581-596

damage mechanisms (rail)

- wear is most common damage mechanism
 - wear \propto (tangential force)*slip
- other damage mechanisms (plastic flow etc) are not significant for types of corrugation that contribute to wheel / rail noise

wavelength-fixing mechanisms (see ref.)

Type	Wavelength-fixing mechanism	Where?	Typical frequency (Hz)	treatments	
				Demonstrably successful	Should be successful
pinned-pinned resonance	pinned-pinned resonance	Straight track, high rail of curves	400-1200	Hard rails, control friction	Increase pinned-pinned frequency so that corrugation would be <20mm wavelength
Rutting	2 nd torsional resonance of driven axles	Low rail of curves	250-400	Friction modifier, hard rails, reduce cant excess, asymmetric profiling in curves	reduce applied traction in curving, improve curving behaviour of vehicles dynamic vibration absorber
Heavy haul	P2 resonance	Straight track or curves	50-100	Hard rails	Reduce cant excess when corrugation is on low rail
Light rail	P2 resonance	Straight track or curves	50-100	increase rail strength and EI	Reduce unsprung mass
Other P2 resonance	P2 resonance	Straight track or high rail in curves	50-100	Hard rails, highly resilient trackforms	Reduce unsprung mass
Trackform-specific	Trackform specific	Straight track or curves	-	Hard rails, friction control	Avoid “peaky” resonances, improved steering

wavelength-fixing mechanisms

- fix wavelength and position along track
- *All* wavelength-fixing mechanisms are constant frequency, not constant wavelength
 - wavelength = speed / frequency
- Wavelength-fixing mechanisms relevant to noise and GBV are:
 - pinned-pinned resonance
 - “rutting”
 - P2 resonance: ground-borne vibration

remainder of presentation

- What standards / specifications exist to control or specify limits on corrugation and acoustic roughness?
 - is there any equivalence between these standards?
- What amplitude of corrugation and acoustic roughness exists?
 - before reprofiling
 - after reprofiling
- How can these be measured?
- Can corrugation removal be satisfactorily controlled during the reprofiling operation?
- What is the effect of reprofiling on noise?

EN / ISO standards relevant to irregularities and wheel / rail noise

- **EN 13231-3:2006**
 - reprofiling of rails
- **EN 15610:2009**
 - rail roughness measurement related to rolling noise generation
- **EN ISO 3095**
 - acoustic type testing of vehicles

wavelength ranges: noise and standards

- human hearing
 - 20Hz to 20kHz
- Standards
 - EN13231:3 reflects limitations of reprofiling
 - acoustic standards reflect
 - limitations of conventional equipment
 - effects of contact patch filtering on short wavelengths

	10m/s (22mph)	50m/s (110mph)
20Hz	500mm	2500mm
20kHz	0.5mm	2.5mm

EN13231-3 : 2006	10mm	1000mm
EN15610 : 2009	3mm	250mm
EN ISO3095 : 2005	3.15mm	630mm

EN 13231-3:2006

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

most significant wavelength ranges for noise

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

0.010mm = 0.4thou

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

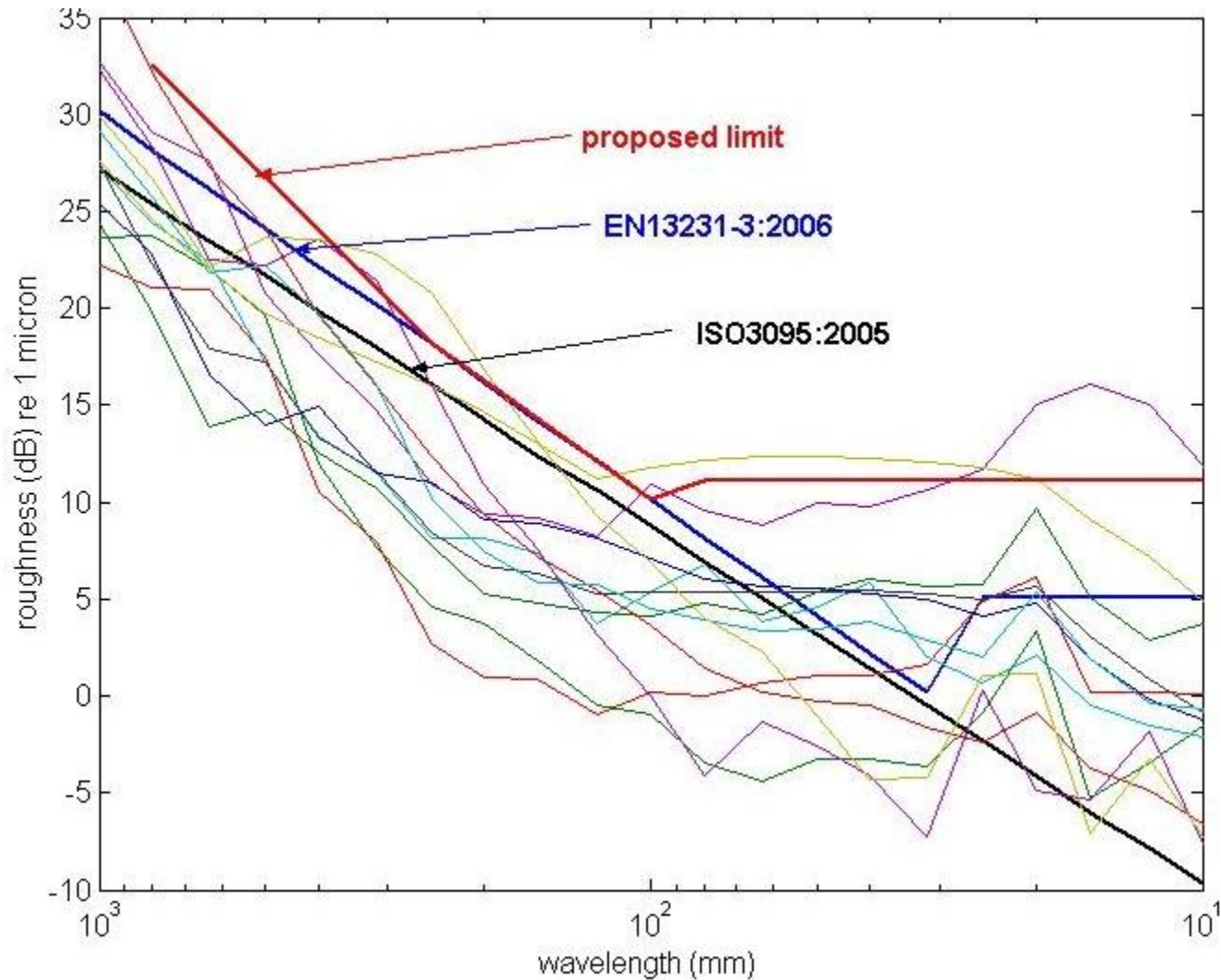
- This is an excellent and practical basis for reprofiling specifications to reduce wheel / rail rolling noise

corrugation / acoustic roughness measurements

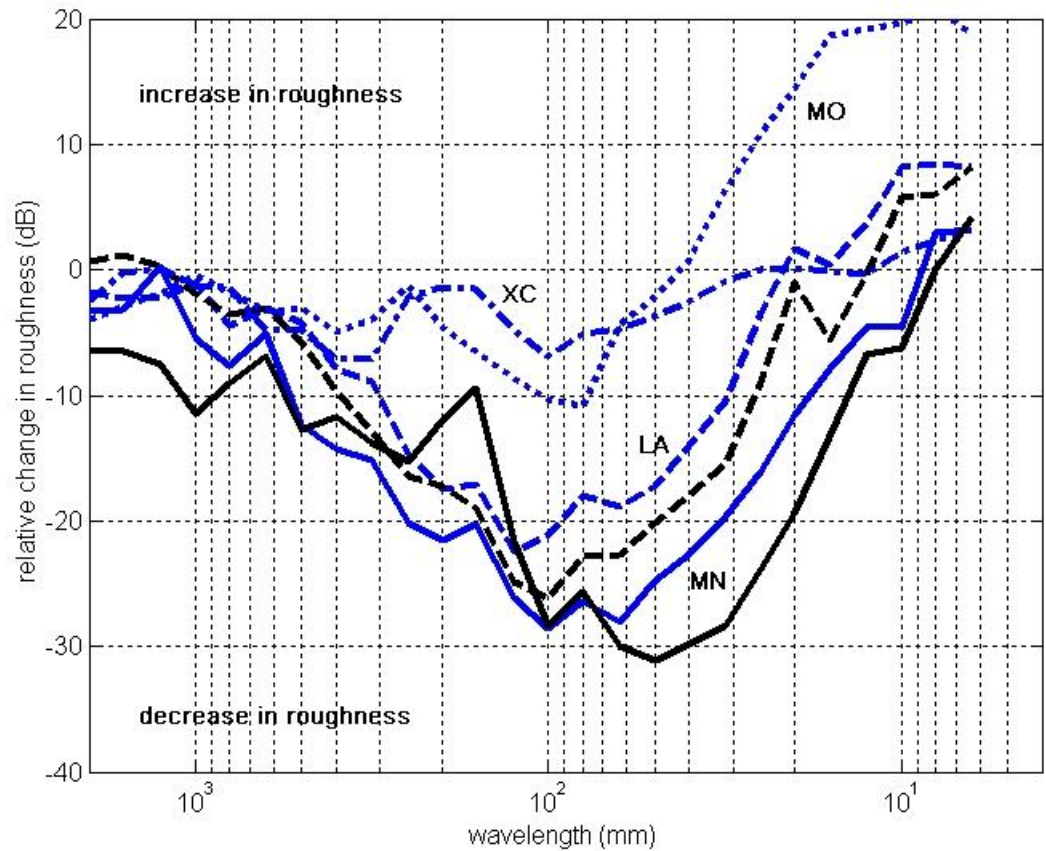


- post-reprofiling measurements
- contributed by users of RailMeasurement equipment
 - worldwide
 - on all types of railway system
 - from major suppliers of reprofiling equipment (grinding and milling): all give both good and bad results
 - using same equipment (CAT)
- **The best results (lowest irregularities, largest change with reprofiling) were obtained where there was a specification that was monitored**

reprofiling standard, acoustic standards and post-reprofiling irregularities



change in roughness with reprofiling



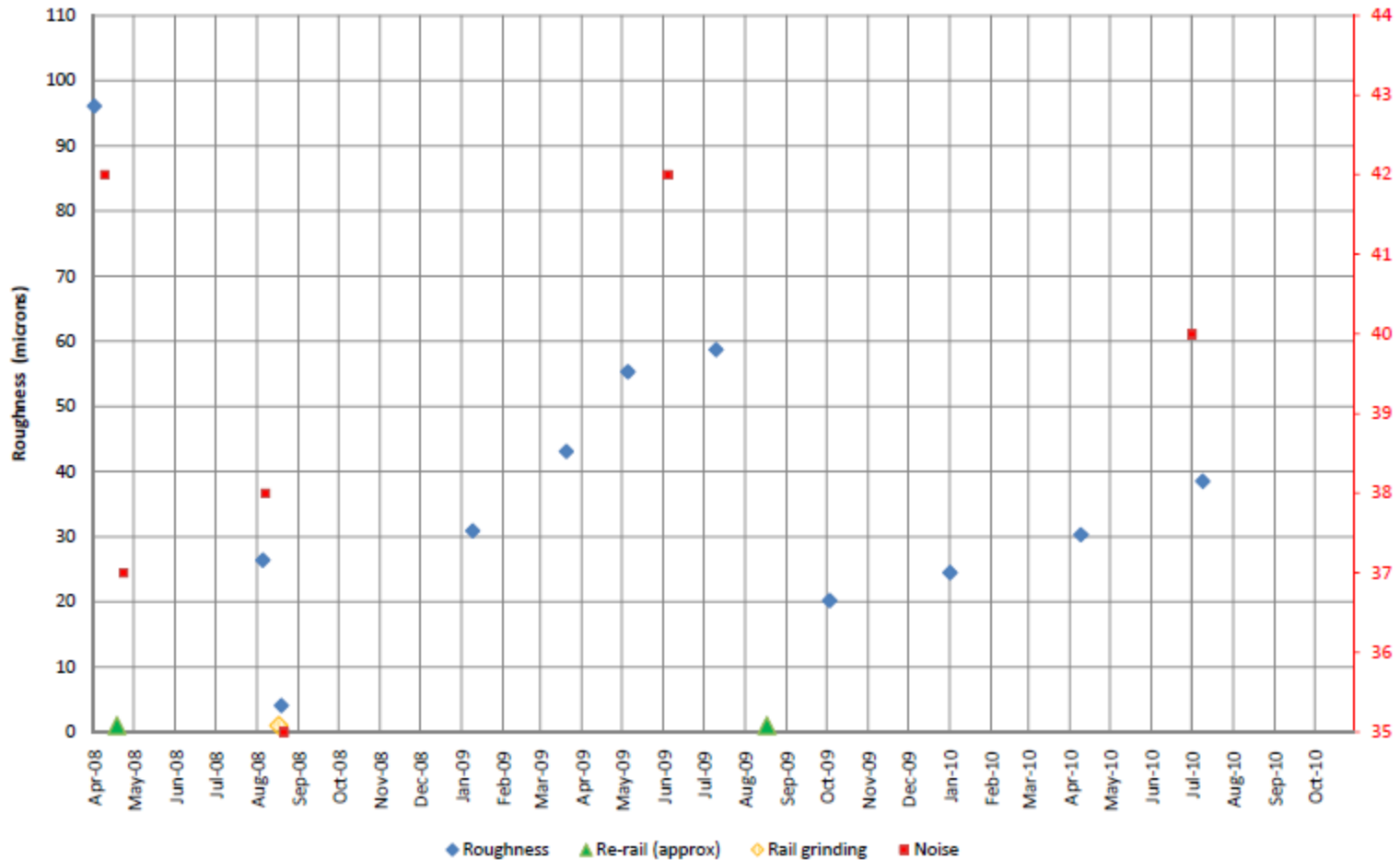
- reprofiling

- can (but doesn't always) reduce irregularities below EN13231-3:2006 level (previous slide)
- rarely reduces irregularities below ISO3095/EN15610 level for 10-30mm wavelength range (previous)
- *usually* significantly reduces irregularities 30-300mm
- usually increases irregularities 10-30mm

long-term monitoring of corrugation, grinding and noise (primarily ground-borne)

- Data from London Underground, with permission
- 4 lines on LU, 24 locations
 - specific locations are not shown
- The main justification for grinding on much of London Underground is noise reduction.
 - monitoring undertaken at some sites for more than a decade
 - first railway system to adopt a CAT for QA of grinding (in 1997)

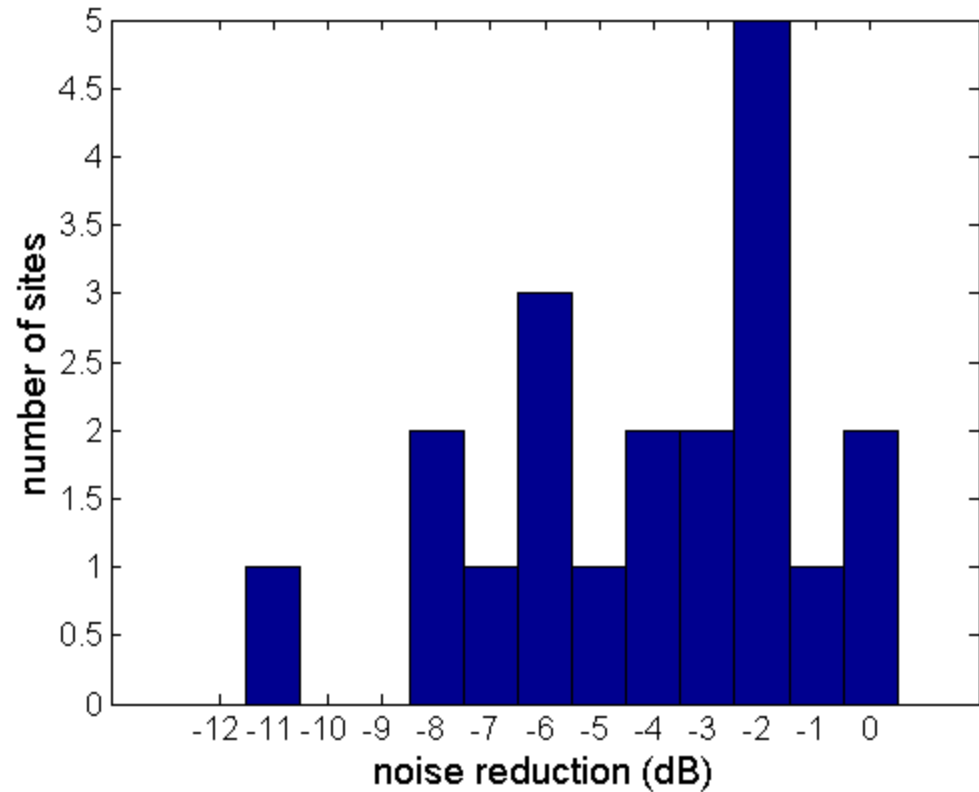
Long-term monitoring of noise and roughness (courtesy of London Underground)



- One site: 3-7dB reduction from grinding or rerailing
- 30 months, two (partial) rerails (!), one grind

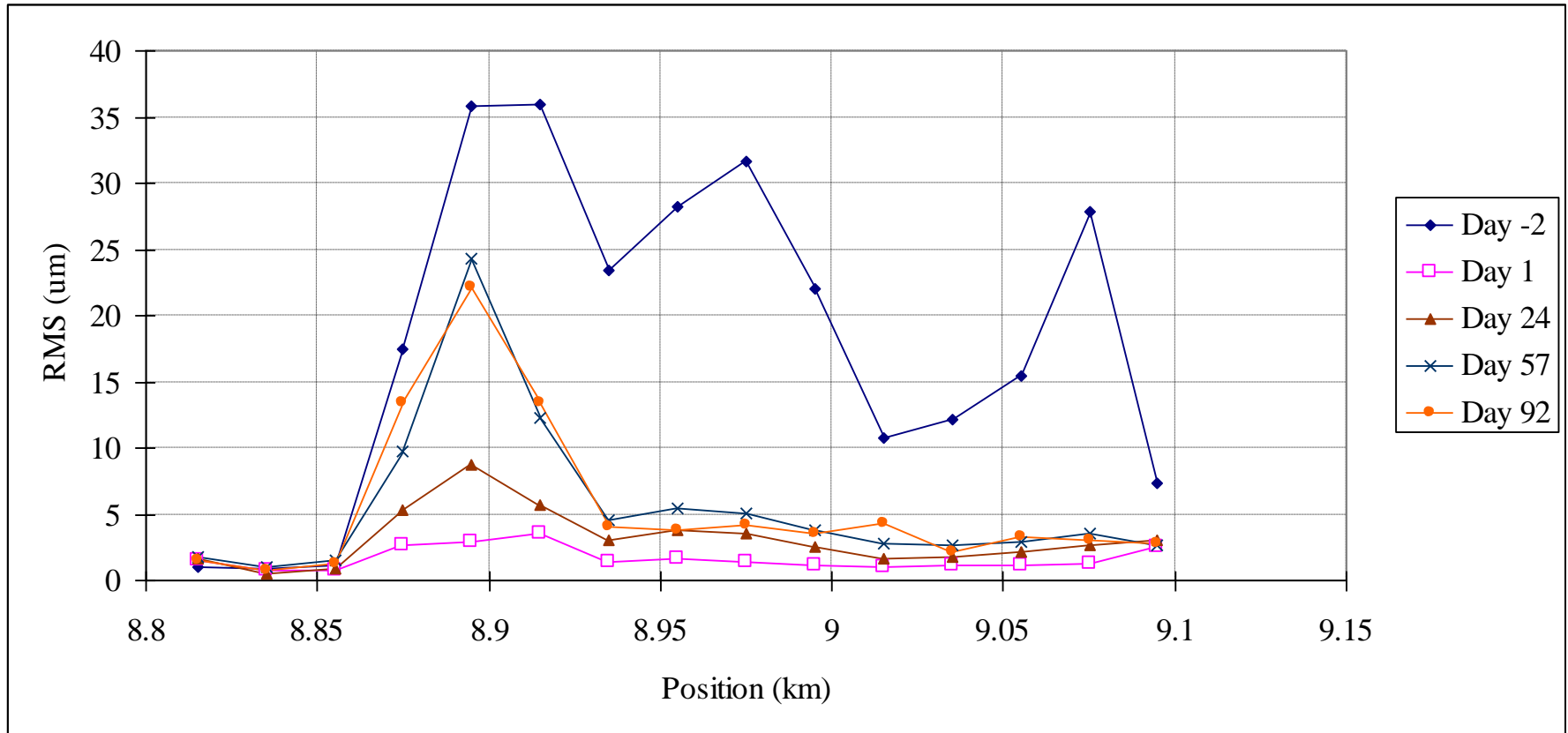
LOCATION		PRE-GRIND	GROUND	POST-GRIND	+6 MONTHS	PRE (dB)	POST (dB)	+6M (dB)	ΔdB
Victoria									
	SB	07/08/2009	09/08/2009	24/08/2009	24/05/2010	43	41	40	-3
	SB	26/05/2009	04/10/2010	no access		45			
	SB	05/02/2009	17/08/2009	25/08/2009	18/02/2010	45	43		-2
	SB	12/05/2009	23/08/2009	23/09/2009		52	51		
	SB	21/07/2009	23/08/2009	23/09/2010		37	37		
	SB	04/03/2009	02/08/2009	14/09/2009	25/03/2010	45	49	43	-2
	NB	04/03/2009	02/08/2009	14/09/2009	25/03/2010	38	36	36	-2
	NB	21/07/2009	23/08/2009	23/09/2010		53	47		-6
	NB	05/02/2009	17/08/2009	25/08/2009	18/02/2010	45	44		-1
	NB	07/08/2009	09/08/2009	24/08/2009	24/05/2010	41	39	37	-4
Central Line									
	IR	14/08/2009	01/04/2010	11/05/2010		44		47	
	EB	24/11/2009	26/02/2010	14/06/2010		39	31		-8
	WB	24/11/2009	26/02/2010	12/04/2010		38	35		-3
Bakerloo Line									
	NB	23/02/2010	21/03/2010	07/04/2010		47	42		-5
	SB	23/02/2010	21/03/2010	07/04/2010		42	42		0
	NB	02/06/2009	01/05/2010	02/06/2010		40	36		-4
	SB	02/06/2009	01/05/2010	02/06/2010		48	41		-7
District Line									
	EB	13/01/2010	08/04/2010	04/05/2010		56	56		0
	EB	09/12/2009	23/02/2010	19/03/2010		54	52		-2
	WB	09/12/2009	03/03/2010	19/03/2010		54	52		-2
	EB	01/02/2010	02/02/2010	19/03/2010		44	38		-6
	WB	01/02/2010	11/02/2010	19/03/2010		46	38		-8
Circle Line									
	OR	01/02/2010	16/02/2010	19/03/2010		57	46		-11
	IR	01/02/2010	18/02/2010	19/03/2010		39	33		-6

**Noise
reduction
(usually
ground-borne
noise i.e.
relatively low
frequency)**



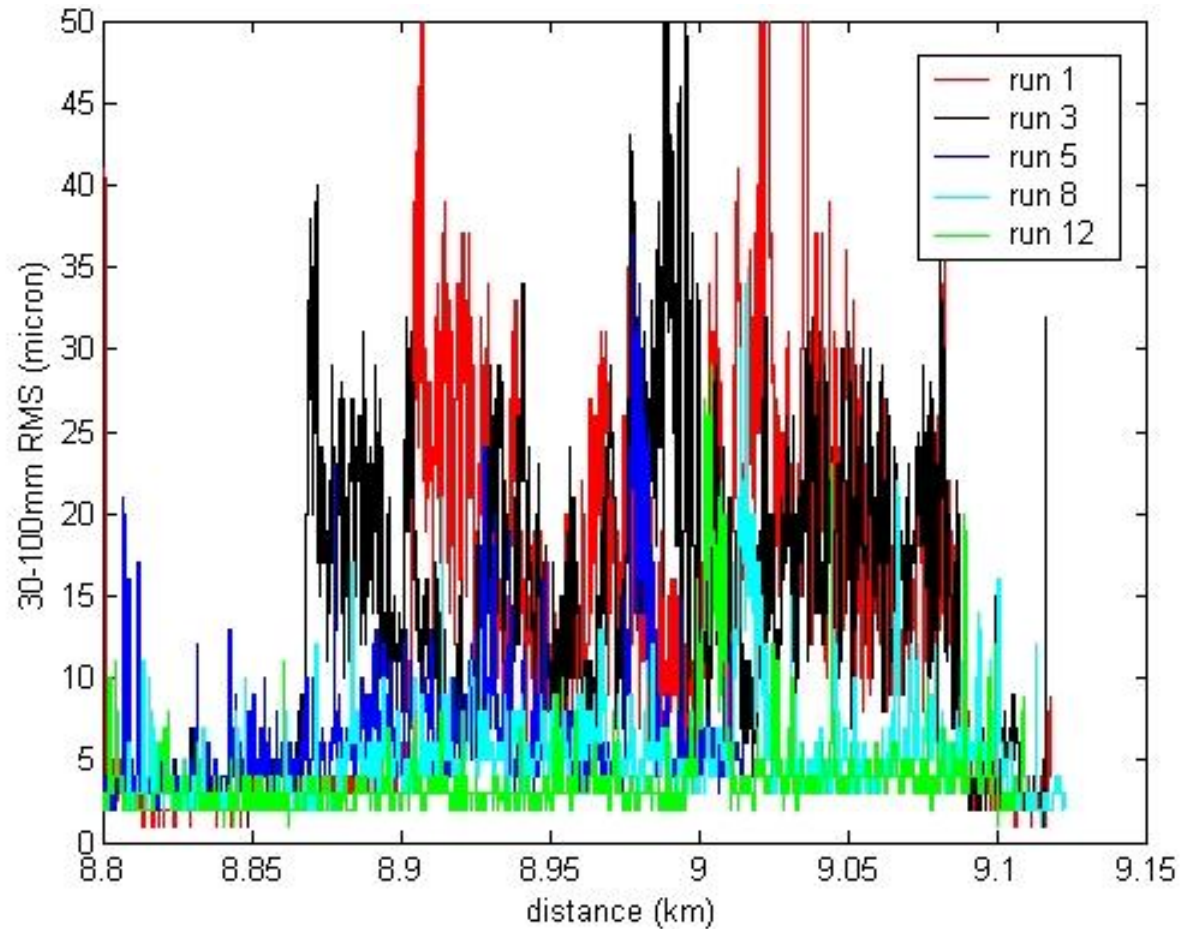
- reduction from grinding is significant, particularly given that noise is primarily ground-borne, therefore low frequency (underground)
- sometimes an increase immediately after grinding, but significant reduction after 6 months
- grinding undertaken to equivalent of EN13231-3:2006 for about a decade, and monitored (with CAT)

development of corrugation (on metro)



- 30-100mm corrugation (measured with CAT)
 - well developed after only 2 months

removal of
corrugation
(same site)
Loram LR
series
grinder



- reduction in 30-100mm corrugation from more than 0.050mm RMS to less than 0.003mm (0.12 thou) RMS in 12 passes
- measurements (at 1mm interval) *during grinding*

Conclusions (1 of 4)

- model including “damage mechanism” and “wavelength fixing mechanism” provides a good method of understanding rail corrugation
- wear is the most common damage mechanism (and most relevant to short wavelength corrugation & noise)
- wavelength-fixing mechanisms most relevant to wheel / rail noise and GBV:
 - P2 resonance: 50-100Hz
 - “rutting” (axle torsion): 250-400Hz
 - pinned-pined resonance: 450-1200Hz

Conclusions (2 of 4)

- acoustics and reprofiling standards exist that are an excellent basis for controlling irregularities that contribute to wheel / rail noise
 - reprofiling standard (2006 version) and acoustics standards are substantially identical
 - all major suppliers *can* reprofile to requirements of the 2006 European reprofiling standard (also all suppliers *may not* do so)
 - a few reprofiling trains have on-board equipment that can demonstrate these standards have been achieved

Conclusions (3 of 4)

- comprehensive measurements (undertaken on London Underground) demonstrate:
 - 0-11dB reduction in noise (mainly ground-borne) following grinding on a wide range of sites
 - consistent increase in corrugation / roughness and noise under traffic, after grinding
 - noise measurements not as comprehensive (in-property noise levels)
- irregularities at levels of a few microns can be and are monitored routinely during reprofiling on some metro systems

Conclusions (4 of 4)

- reprofiling (typical grinding and milling)
 - greatly reduces irregularities in 30-300mm wavelength range
 - typically *increases* amplitude of irregularities at 10-30mm wavelength (“stone signature”)
- The best results from reprofiling are consistently obtained where and when there is an objective specification that can be and is monitored.

acknowledgements

- John Edwards and James Shepherd, Noise and Vibration Engineers, London Underground
- Prof Xuesong Jin and colleagues, SWJTU, Chengdu for post-grind monitoring of corrugation
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