Characterization of Roughness on Urban and Low-Speed Roadways

By

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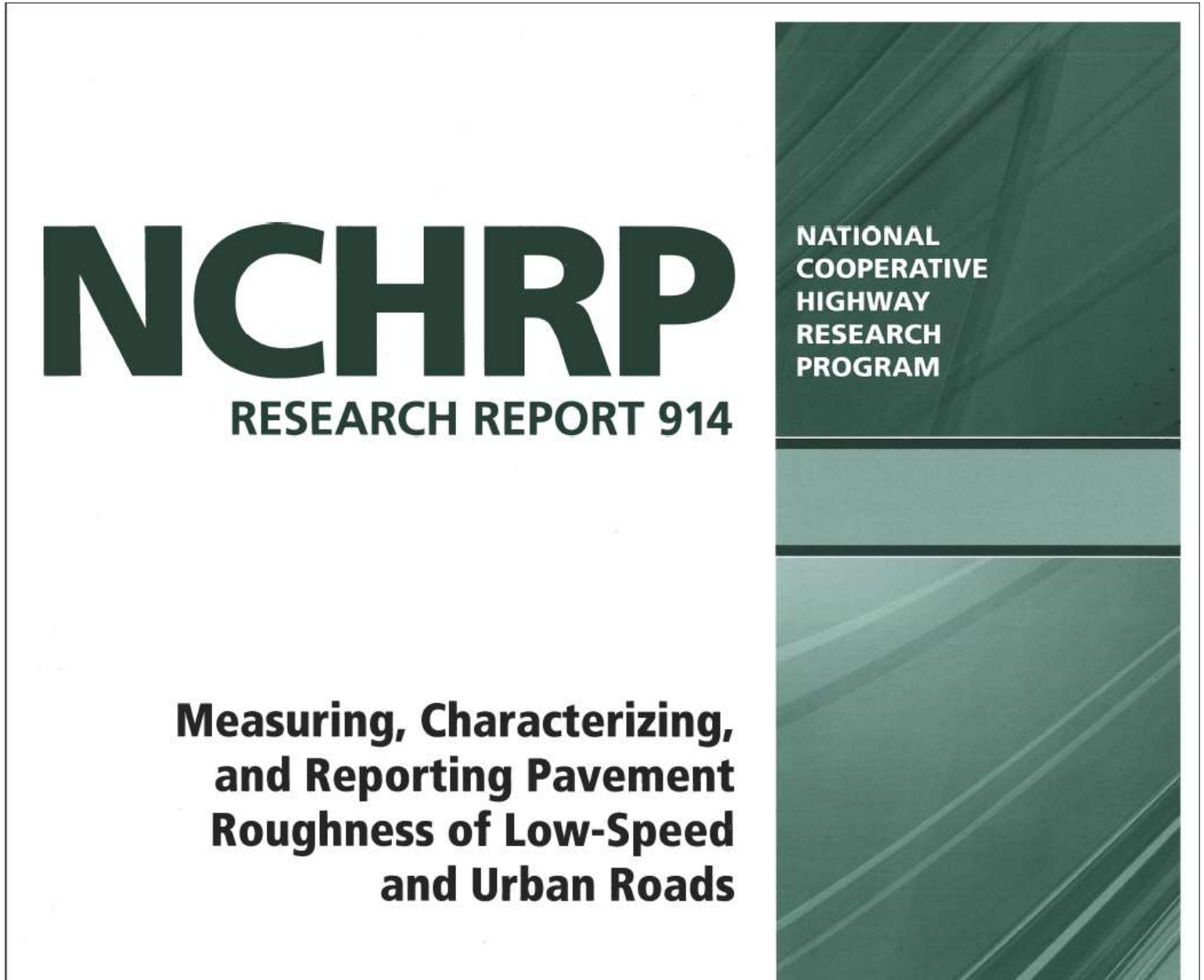
RPUG Road Profile Users' Group

NCHRP 10-93



COTR:
Amir Hanna

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NCHRP 10-93 Approach

Valid measurement of longitudinal profile is at the core of the approach.

- Reproducibility/Time Stability
- Versatility
- Diagnostics

Characterization of the roughness will depend on profile, not the roughness source.

- Vehicle response (e.g., ride) is of primary importance.
- Tools are needed to identify roughness sources.

Ride Experiment

- Relate objective measurement of ride vibration on urban and low-speed roads to roughness.
- Use standard measures of “discomfort” caused by vibration.
- Seek correlation to roughness.

Ride Experiment

- 29 Test sections
  - 6 routes
  - functional class 3 and 4
  - speed limit 30-55 mph

Route	Test Sections	County	Functional Class	Speed Limit Range (mi/hr)
Jackson Road/Huron Street	3	Washtenaw	3	35
Grand River (M-5)	5	Wayne	3	35
Michigan Ave. (US-12)	9	Wayne	3	30-45
Fort Street (M-85)	4	Wayne	3	30-50
West Grand River	6	Livingston	4	30-55
M-52	2	Washtenaw	4	30

Source: NCHRP Rpt. 914

Test Vehicles

Source: NCHRP Rpt. 914

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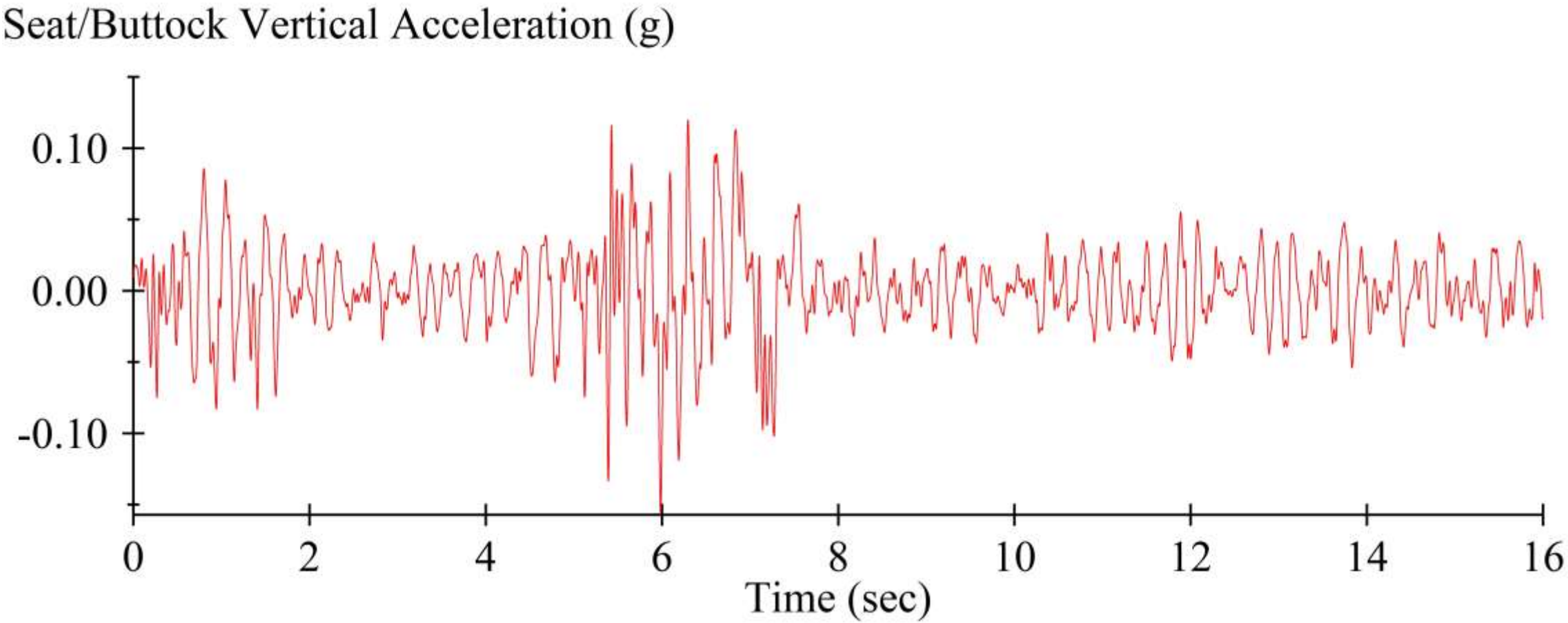
Instrumentation: Driver/Vehicle Interface Accelerations

Source: NCHRP Rpt. 914

Instrumentation: Profiler

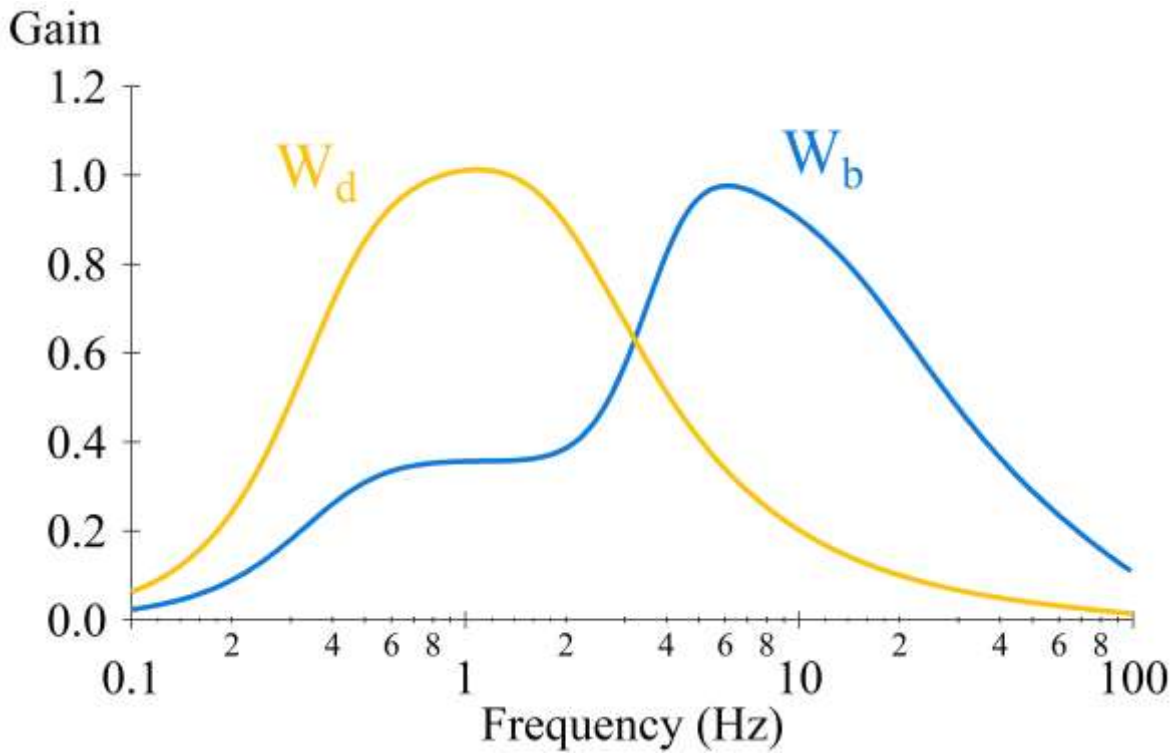
Source: NCHRP Rpt. 914

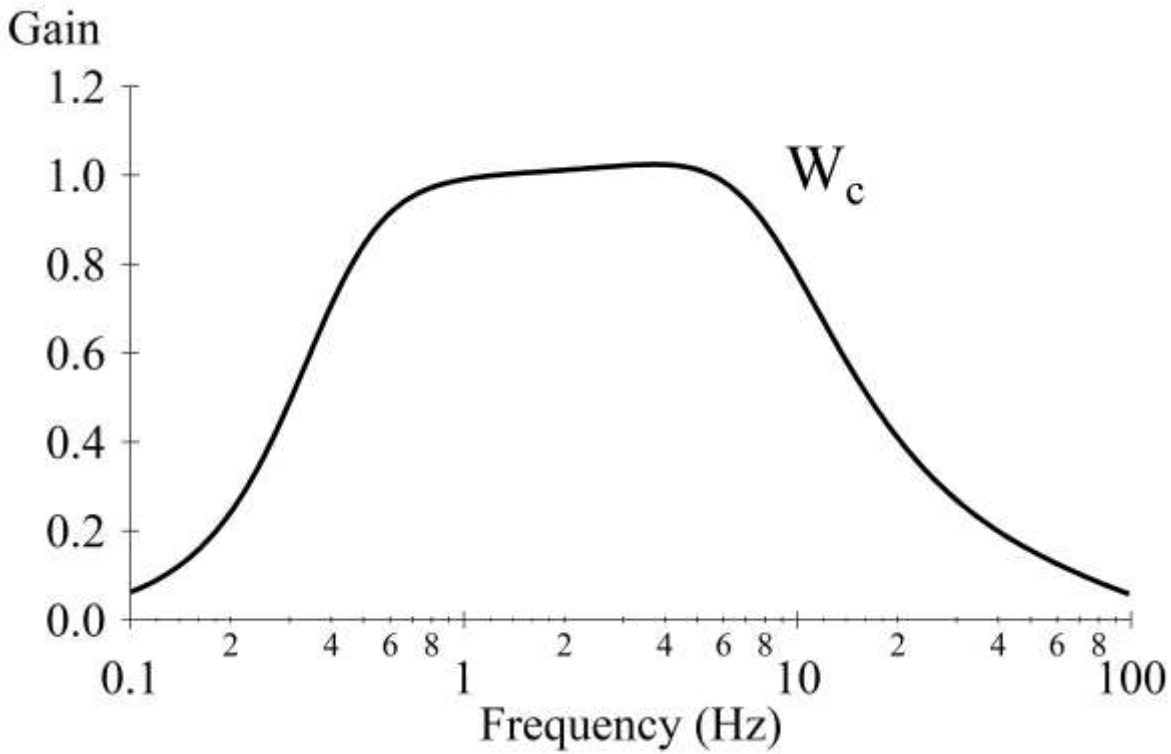
Accelerometer Output



Source: NCHRP 10-93

SAE 2834/ISO 2631 Frequency Weighting





Source: NCHRP Rpt. 914

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SAE 2834/ISO 2631 Frequency Weighting

Interface	Direction	Weighting Function	Multiplying Factor
Seat/buttock	Longitudinal	W_d	1.0
	Lateral	W_d	1.0
	Vertical	W_b	1.0
Seat/back	Longitudinal	W_c	0.8
	Lateral	W_d	0.5
	Vertical	W_d	0.4
Floor/foot	Vertical	W_b	0.4

Source: NCHRP Rpt. 914

“Rough” Ride Metrics

Root Mean Square Weighted Acceleration: $$rmsa_w = \left[\frac{1}{N} \sum_{i=1}^{N} a^2{}_w(i) \right]^{\frac{1}{2}}$$

Point Vibration Total:

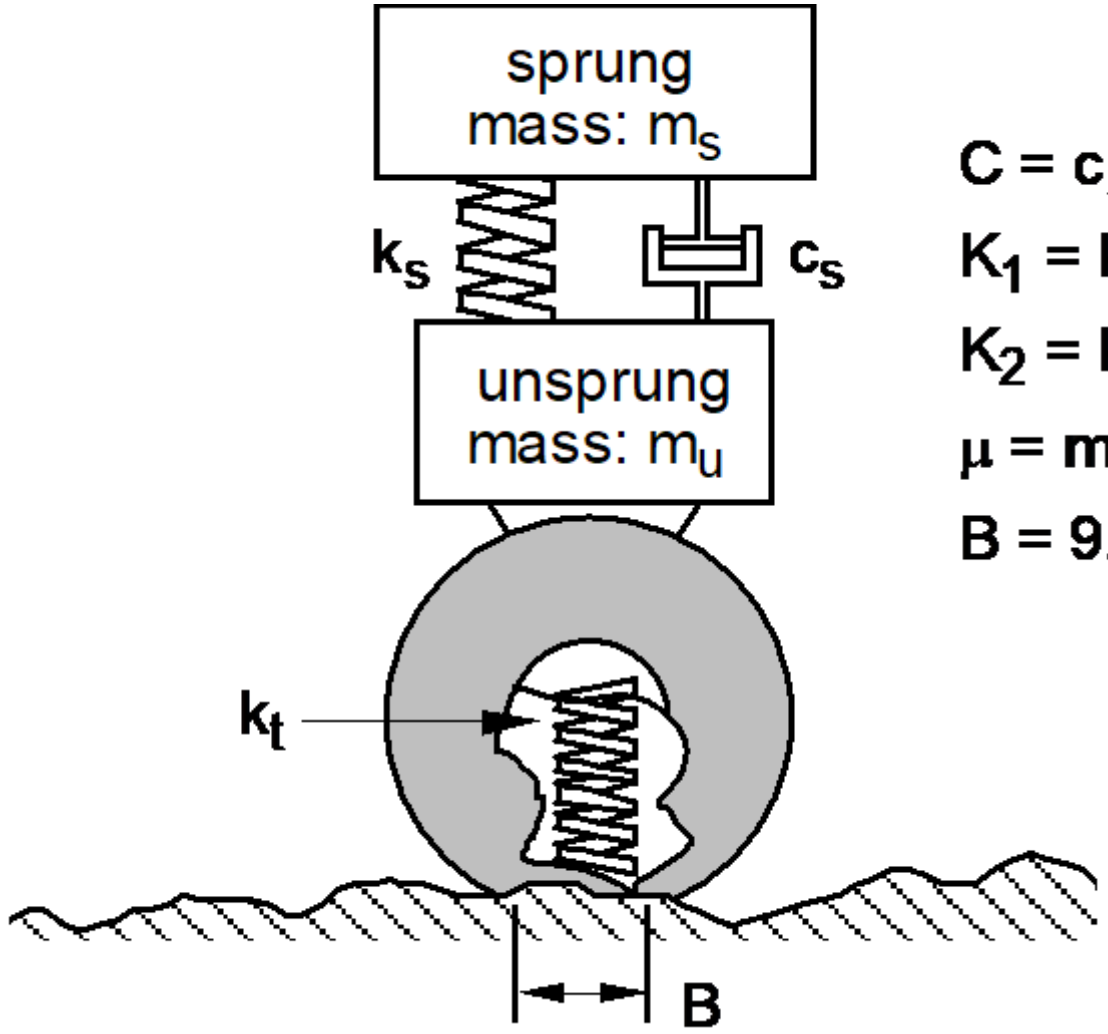
$$PV = \left(k^2{}_x rmsa^2{}_{wx} + k^2{}_y rmsa^2{}_{wy} + k^2{}_z rmsa^2{}_{wz} \right)^{1/2}$$

Overall Vibration Total: $$OVT = \left(PV^2{}_{ff} + PV^2{}_{sbk} + PV^2{}_{sbt} \right)^{1/2}$$

* Stay tuned for “Transient” metrics.

Source: ISO 2631/SAE J2834

“Golden Car” Model



$C = c_s/m_s = 6.0\ sec^{-1}$

$K_1 = k_t/m_s = 653\ sec^{-2}$

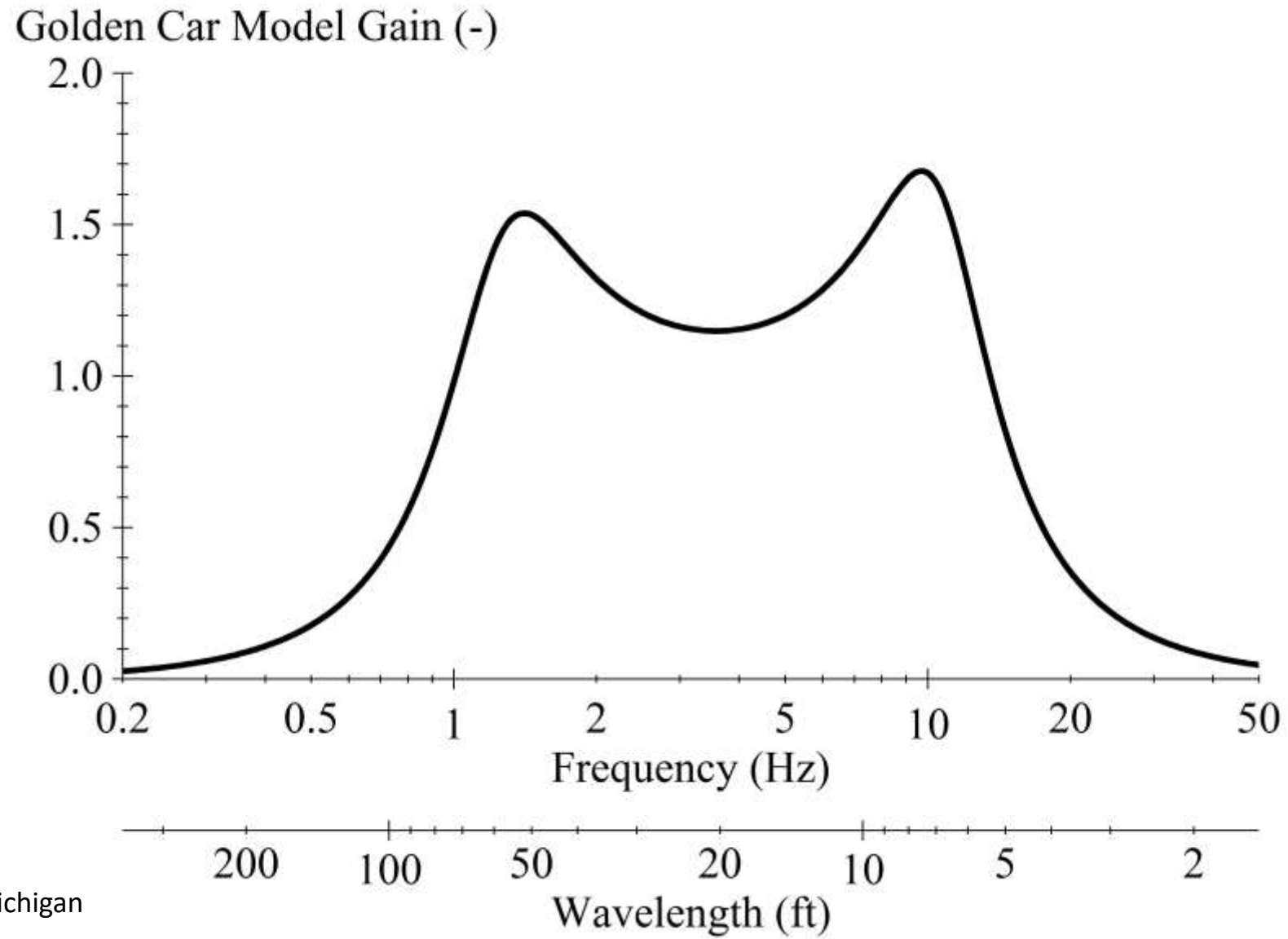
$K_2 = k_s/m_s = 63.3\ sec^{-2}$

$\mu = m_u/m_s = 0.15$

$B = 9.84\ in$

Sayers, M.W., “On the Calculation of International Roughness Index from Longitudinal Road Profile.” *Transportation Research Record 1501* (1995) pp. 1-12.

Golden Car Frequency Response



Correlation to Discomfort

Left IRI:

Discomfort Quantity	mid-sized sedan RMS Resid. (g)	R^2	SUV RMS Resid. (g)	R^2	full-sized van RMS Resid. (g)	R^2
$rmsa_{wzff}$	0.0065	0.796	0.0077	0.778	0.0071	0.798
$rmsa_{wzsbt}$	0.0036	0.866	0.0057	0.820	0.0048	0.699
PVT_{sbt}	0.0033	0.891	0.0057	0.827	0.0068	0.618
OVT	0.0046	0.897	0.0075	0.821	0.0096	0.643

MRI:

Discomfort Quantity	mid-sized sedan RMS Resid. (g)	R^2	SUV RMS Resid. (g)	R^2	full-sized van RMS Resid. (g)	R^2
$rmsa_{wzff}$	0.0081	0.683	0.0087	0.712	0.0076	0.766
$rmsa_{wzsbt}$	0.0052	0.722	0.0068	0.741	0.0055	0.600
PVT_{sbt}	0.0047	0.782	0.0065	0.778	0.0074	0.548
OVT	0.0065	0.791	0.0085	0.770	0.0104	0.583

Source: NCHRP Rpt. 914

Correlation to Discomfort

$GCARS_{35}$:

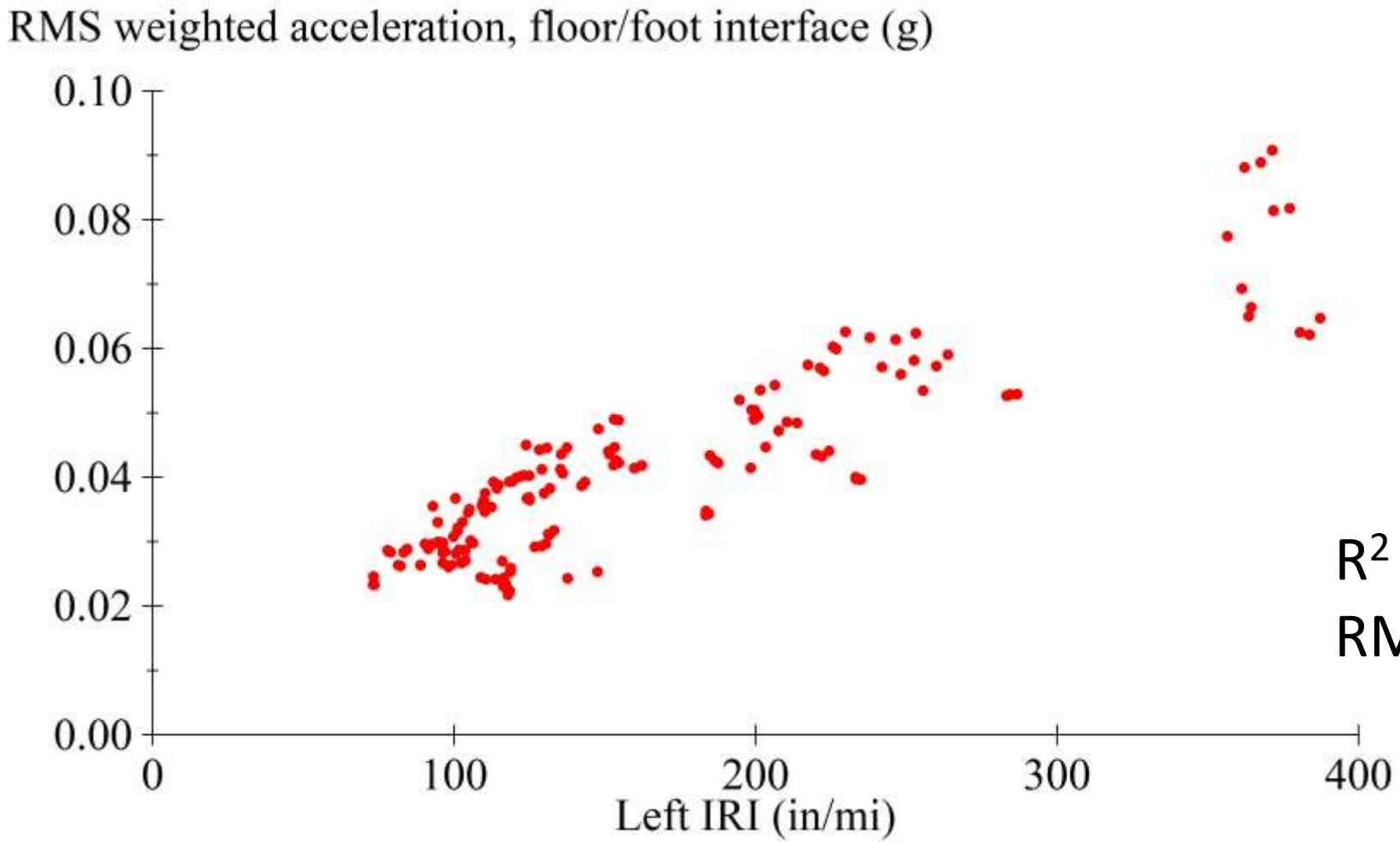
Discomfort Quantity	mid-sized sedan RMS Resid. (g)	mid-sized sedan R^2	SUV RMS Resid. (g)	SUV R^2	full-sized van RMS Resid. (g)	full-sized van R^2
$rmsa_{wzff}$	0.0059	0.832	0.0065	0.838	0.0075	0.772
$rmsa_{wzsbt}$	0.0035	0.874	0.0044	0.891	0.0047	0.710
PVT_{sbt}	0.0040	0.846	0.0053	0.849	0.0073	0.554
OVT	0.0057	0.842	0.0069	0.849	0.0105	0.576

$GCARV_V$:

Discomfort Quantity	mid-sized sedan RMS Resid. (g)	mid-sized sedan R^2	SUV RMS Resid. (g)	SUV R^2	full-sized van RMS Resid. (g)	full-sized van R^2
$rmsa_{wzff}$	0.0066	0.790	0.0063	0.852	0.0063	0.840
$rmsa_{wzsbt}$	0.0049	0.757	0.0046	0.881	0.0046	0.719
PVT_{sbt}	0.0047	0.788	0.0050	0.868	0.0069	0.600
OVT	0.0066	0.787	0.0066	0.863	0.0097	0.634

Source: NCHRP Rpt. 914

Left IRI versus Floor/Foot Acceleration



$R^2 = 0.799$

RMS resid. = 0.0064 g

Source: NCHRP Rpt. 914

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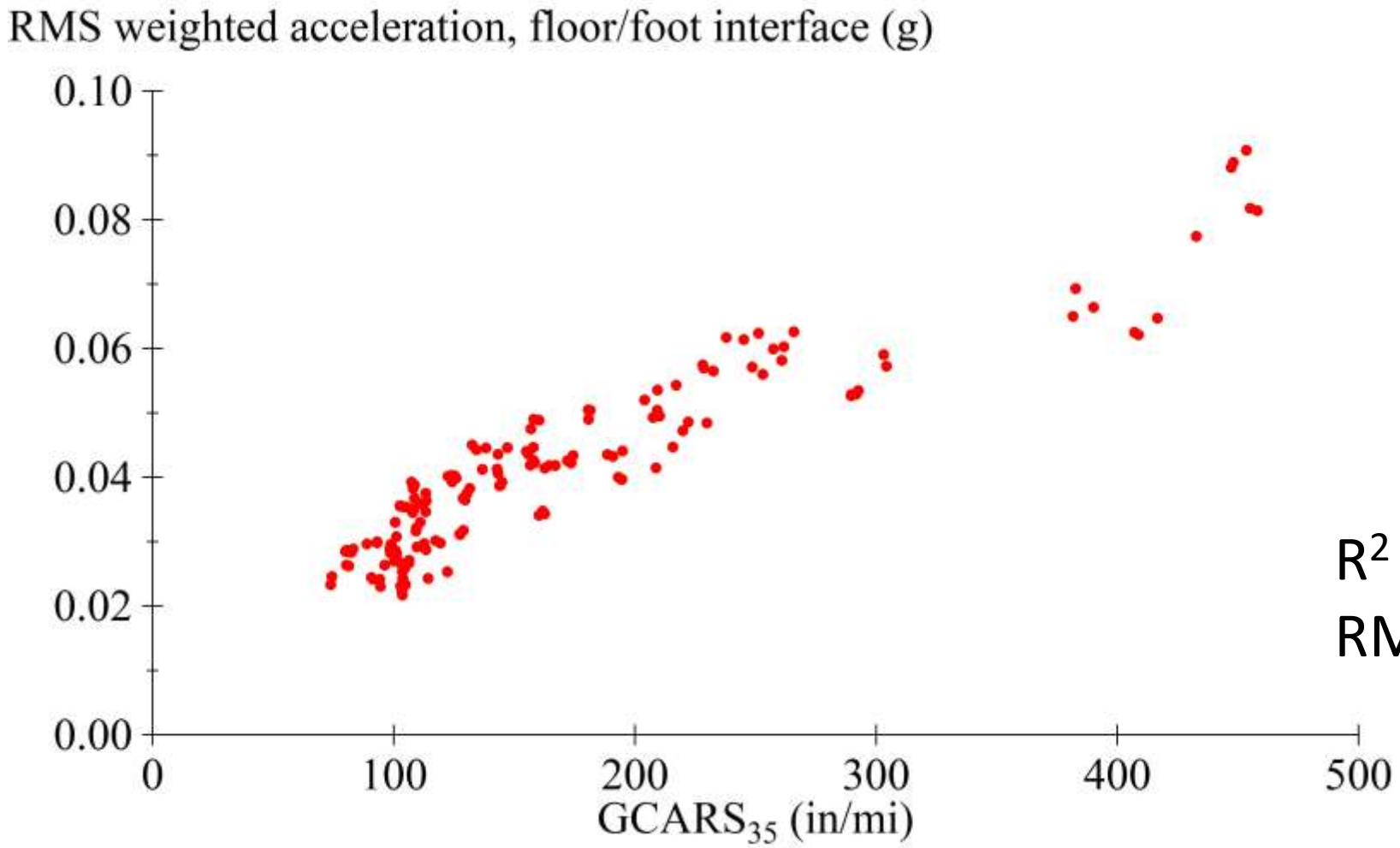
$GCARS_{35}$ versus Floor/Foot Acceleration



$R^2 = 0.866$

RMS resid. = 0.0052 g

Source: NCHRP 10-93

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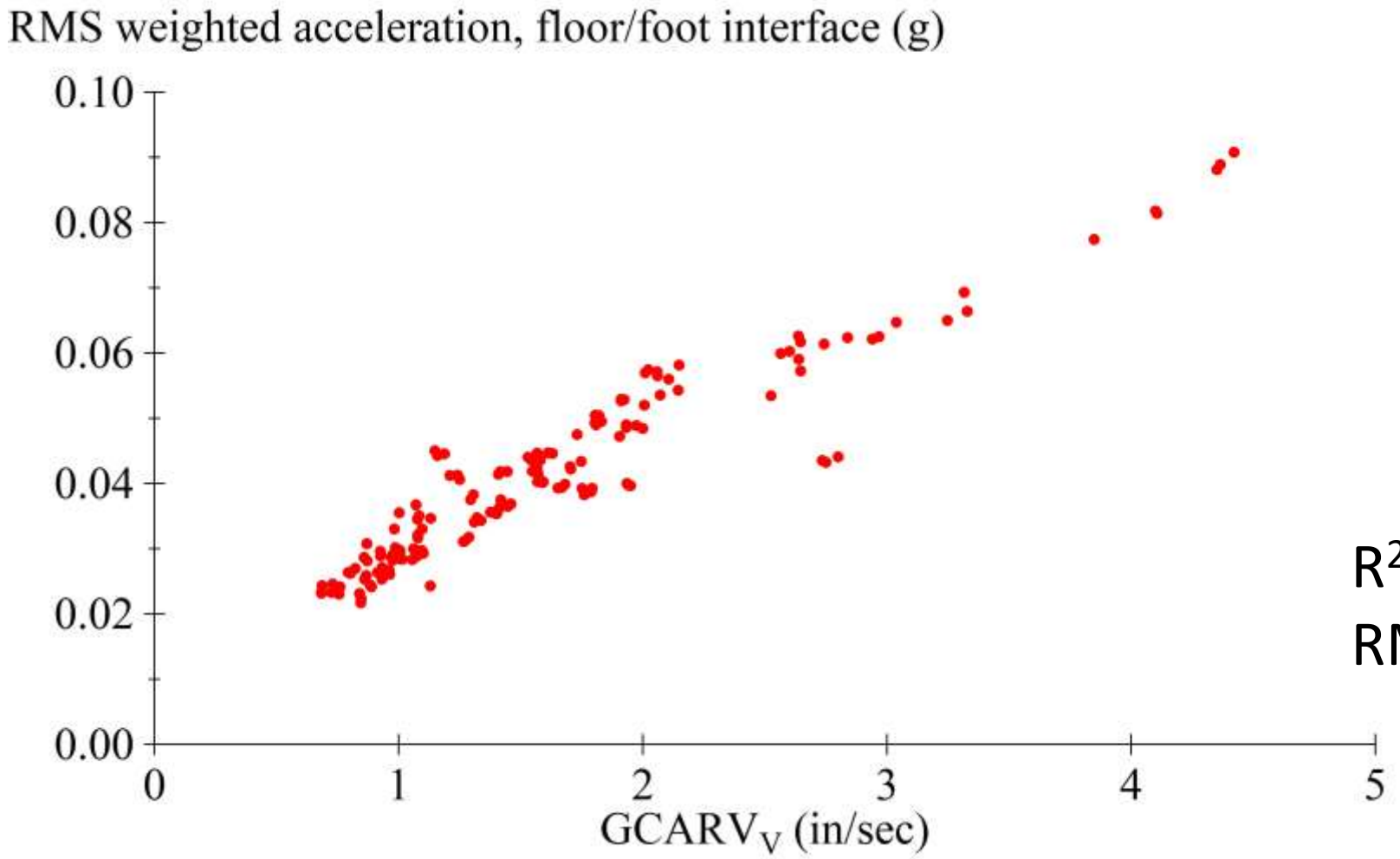
$GCARV_V$ versus Floor/Foot Acceleration



$R^2 = 0.899$

RMS resid. = 0.0046 g

Source: NCHRP 10-93

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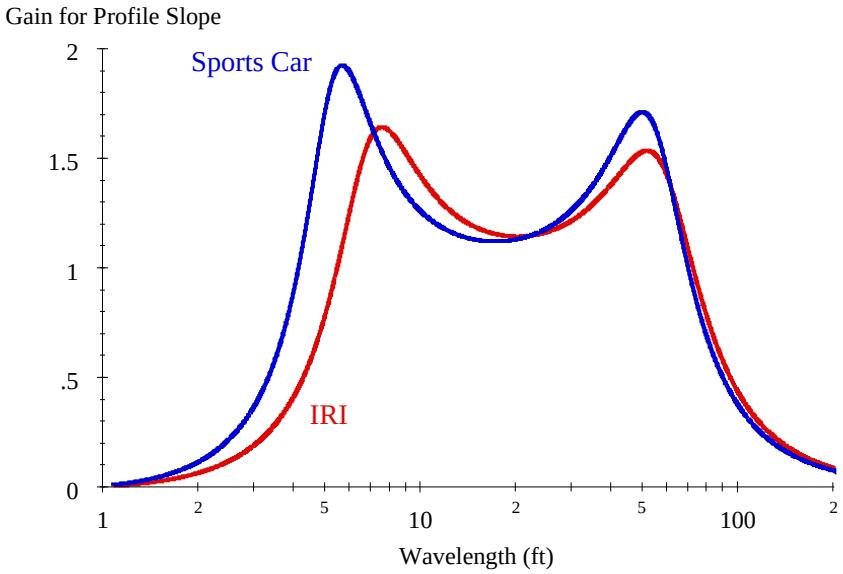
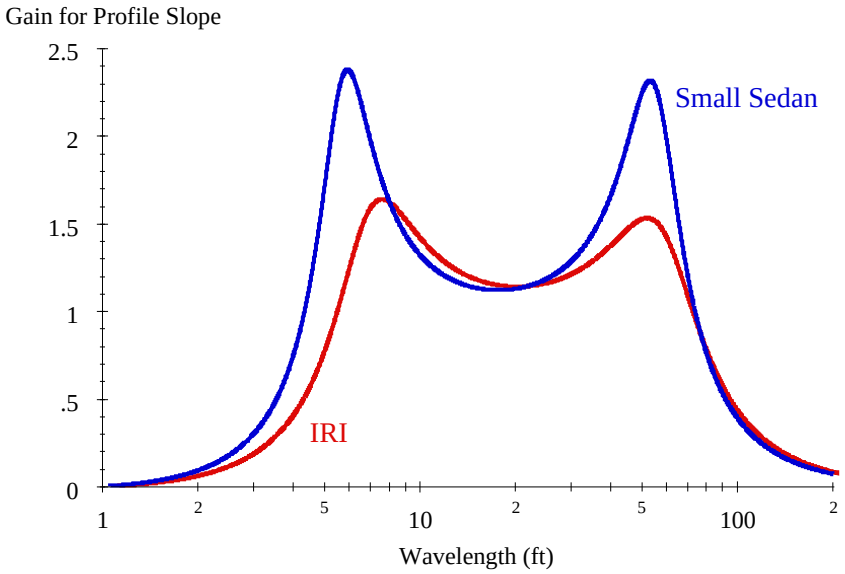
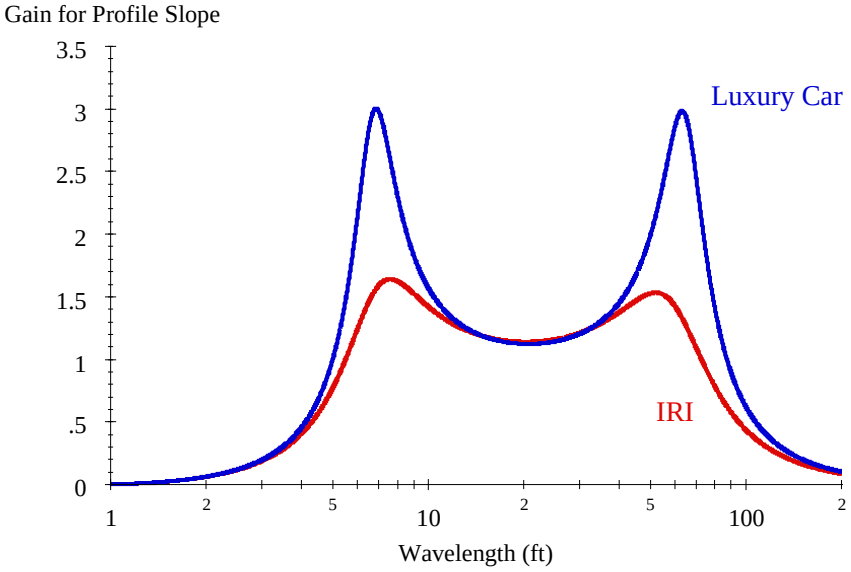
Technical Issues

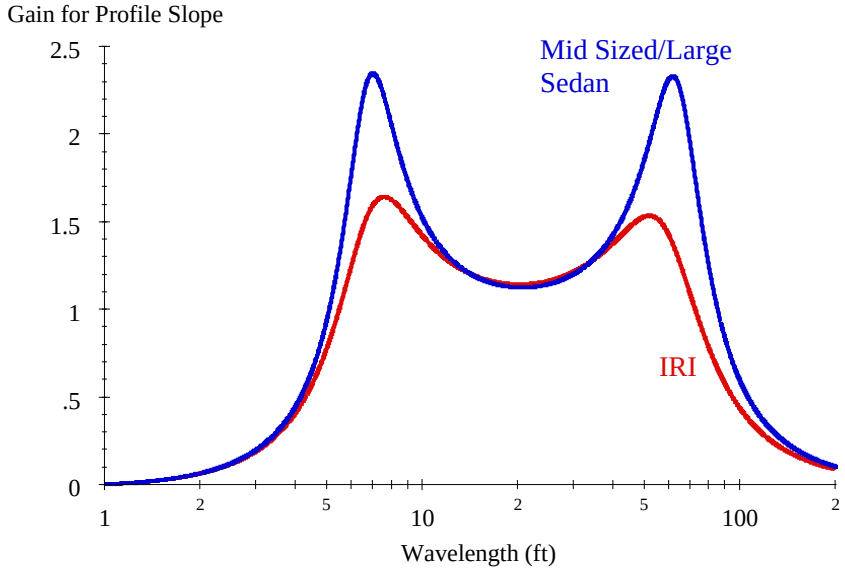
- Limited test vehicles.
- Other responses.
- Thresholds.
- Passengers.
- Localized roughness.

IRI Generality









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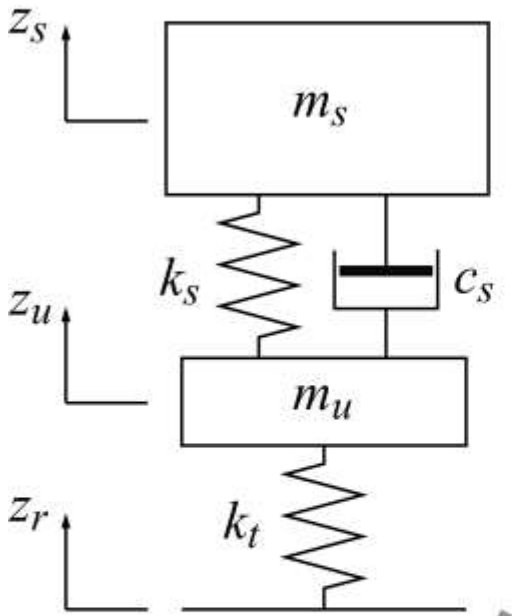
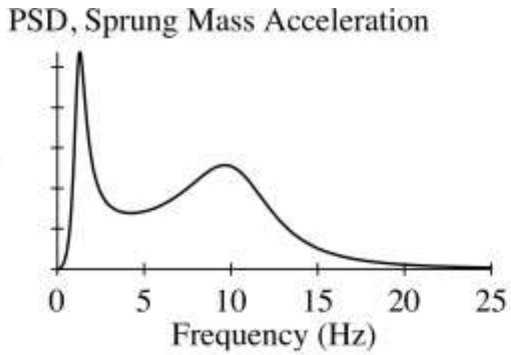
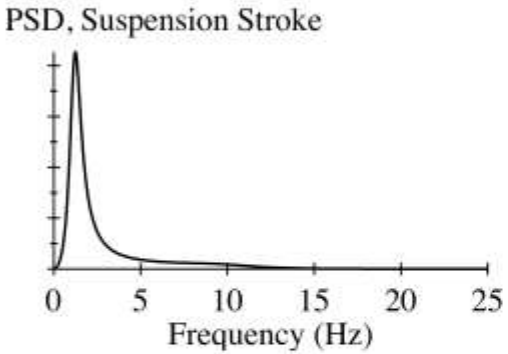
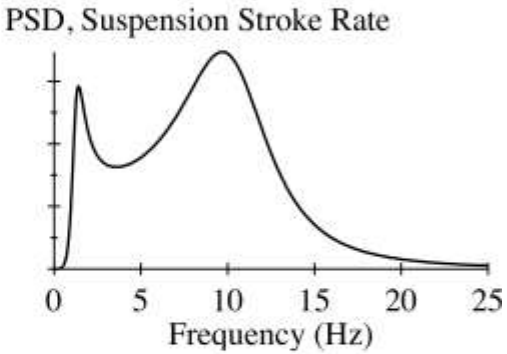
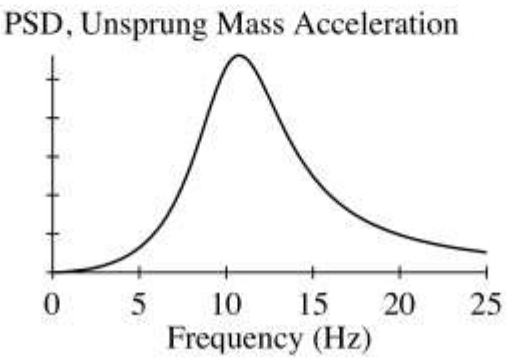
Other Responses

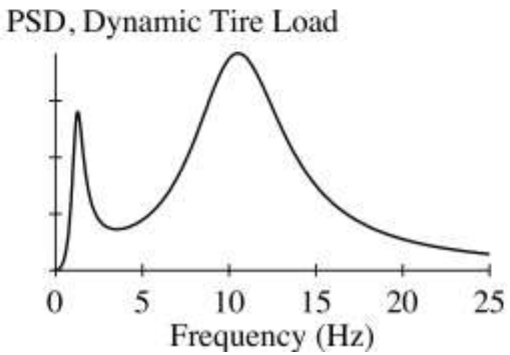






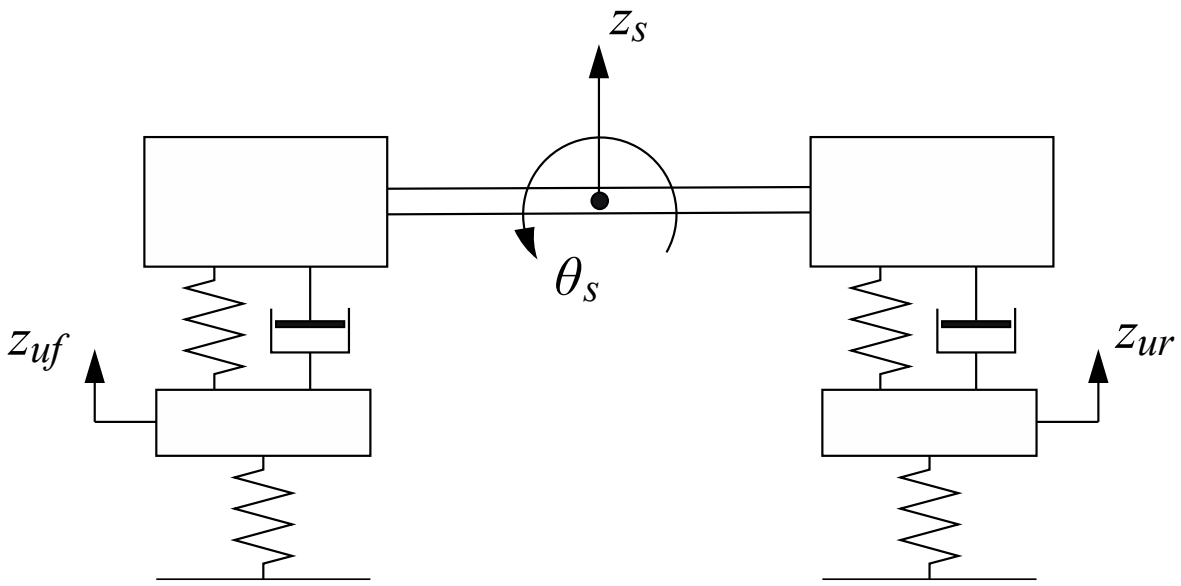


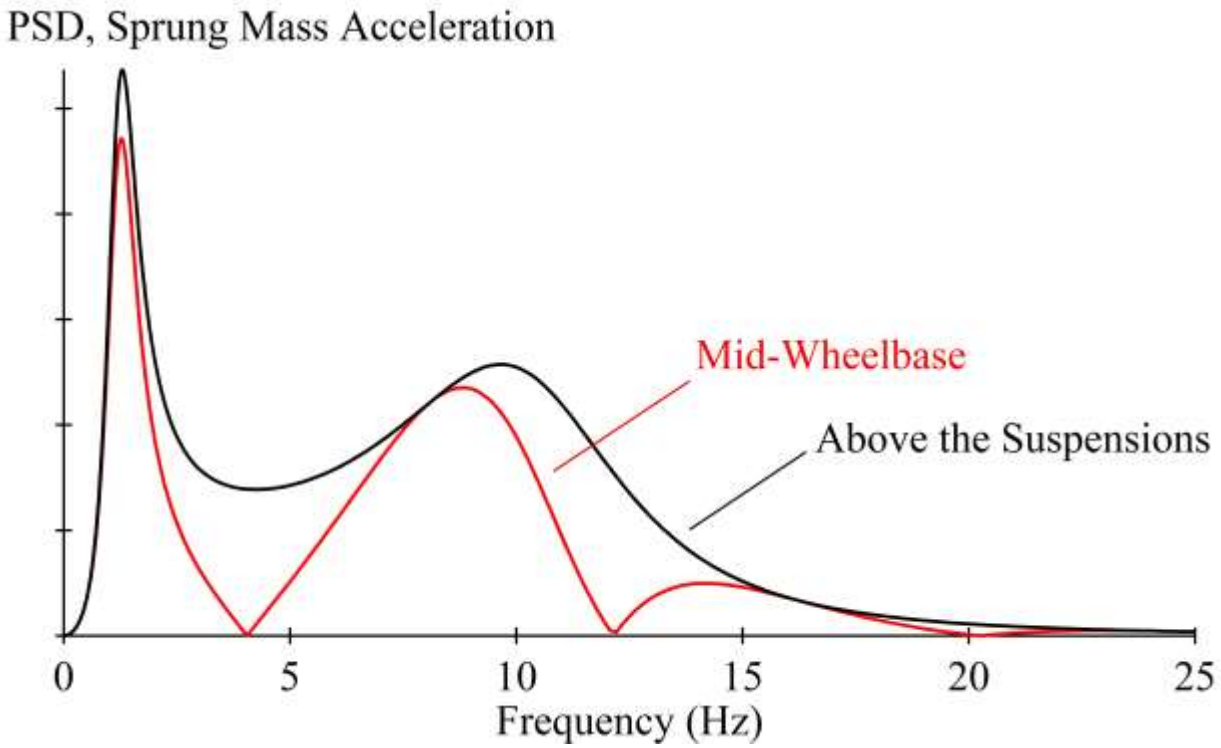




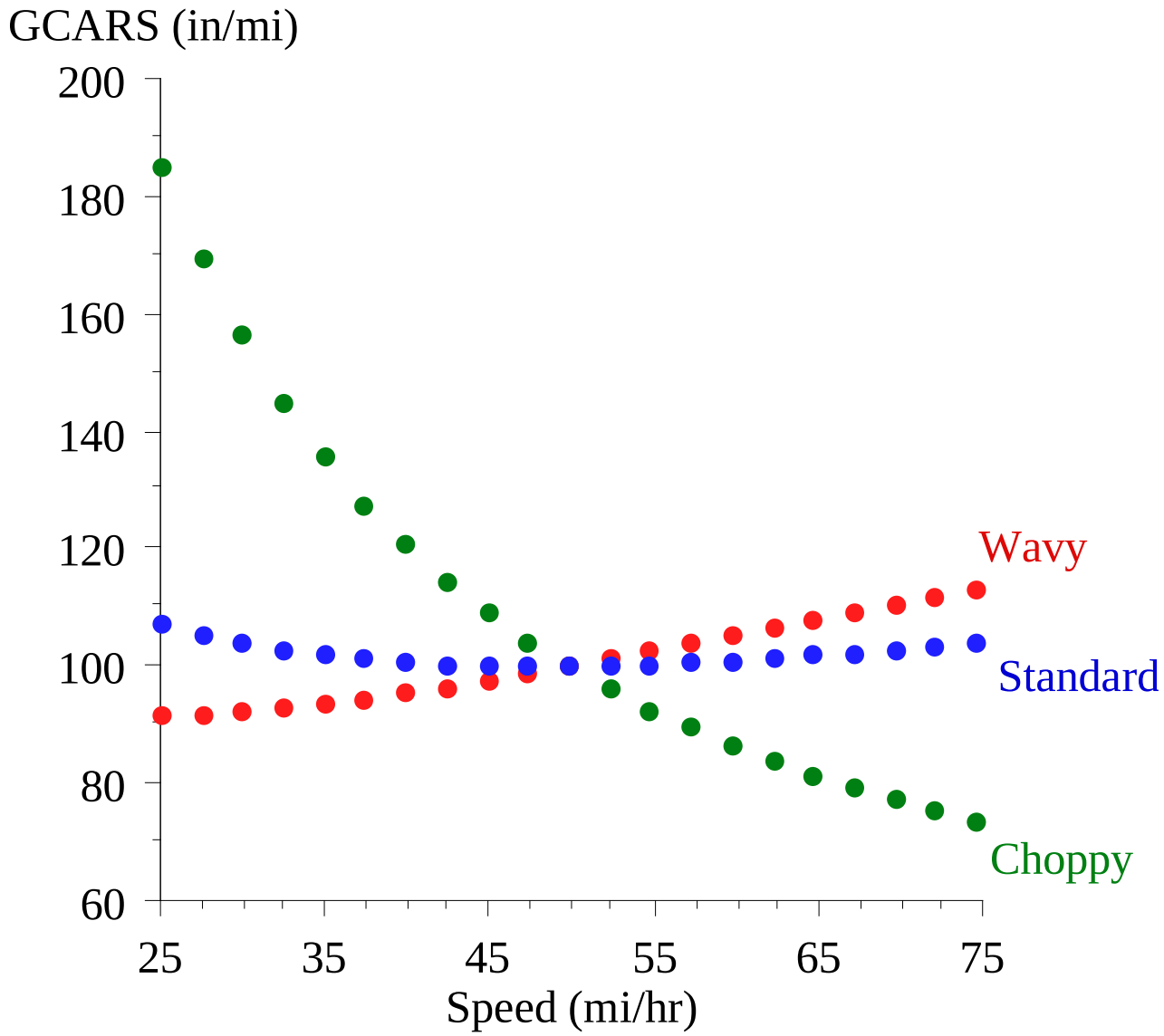
Source: NCHRP Rpt. 914

Other Locations





Thresholds: Meaning of “inches/mi”



Karamihas, S.M., “Simulation Speed and Its Implications to the Relevance of the IRI.” American Society for Testing and Materials STP 1555 (2012) pp. 248–266.

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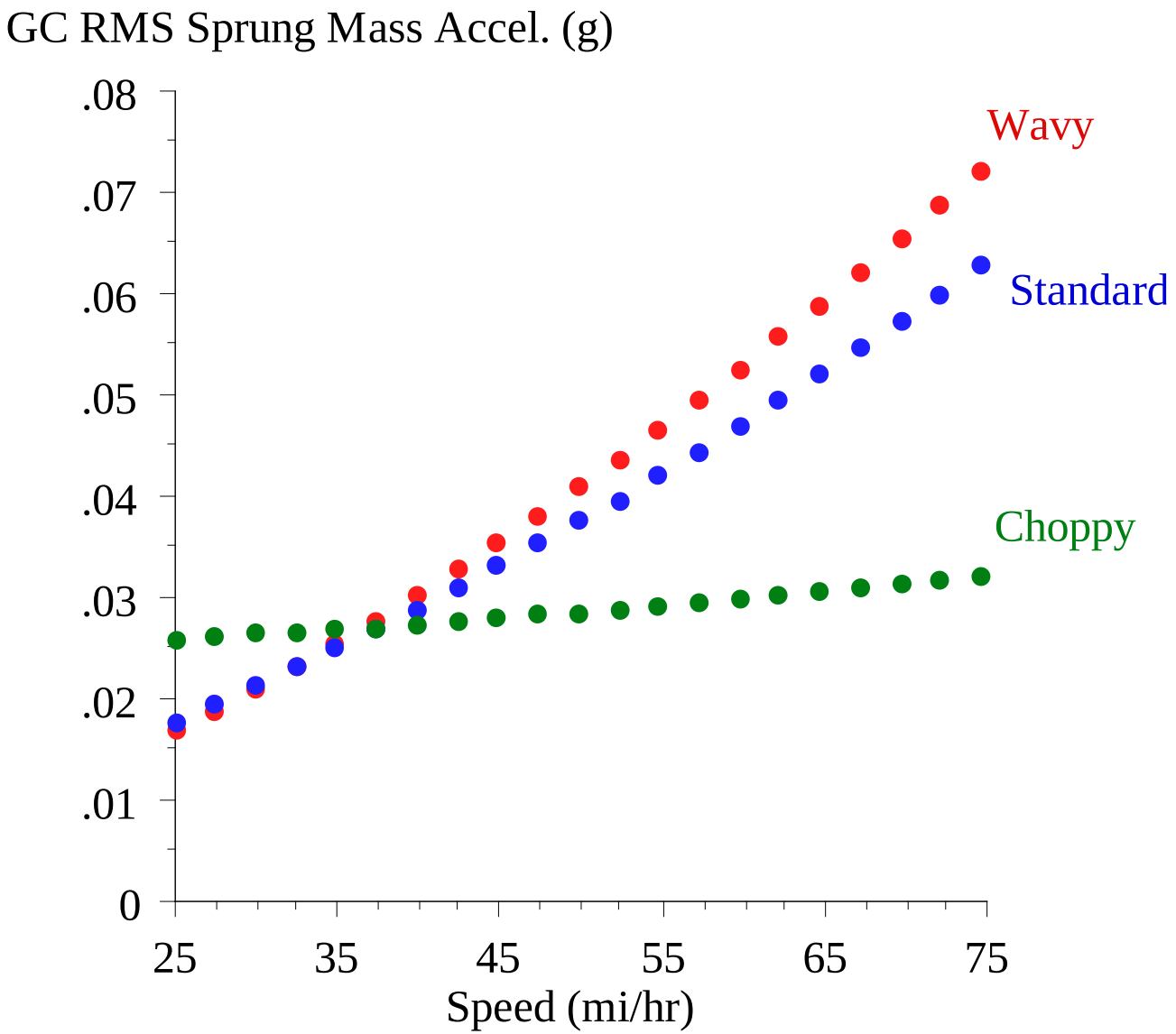


Karamihas, S.M., “Simulation Speed and Its Implications to the Relevance of the IRI.” American Society for Testing and Materials STP 1555 (2012) pp. 248–266.

Transient Ride Metrics

Root Mean Quad Weighted Acceleration: $$rmqa_w = \left[\frac{1}{N} \sum_{i=1}^{N} a_w^4(i) \right]^{\frac{1}{4}}$$

Maximum Transient Vibration: $$rmsa_{w,T}(j) = \left[\frac{1}{M} \sum_{i=j}^{j+M-1} a_w^2(i) \right]^{\frac{1}{2}}$$

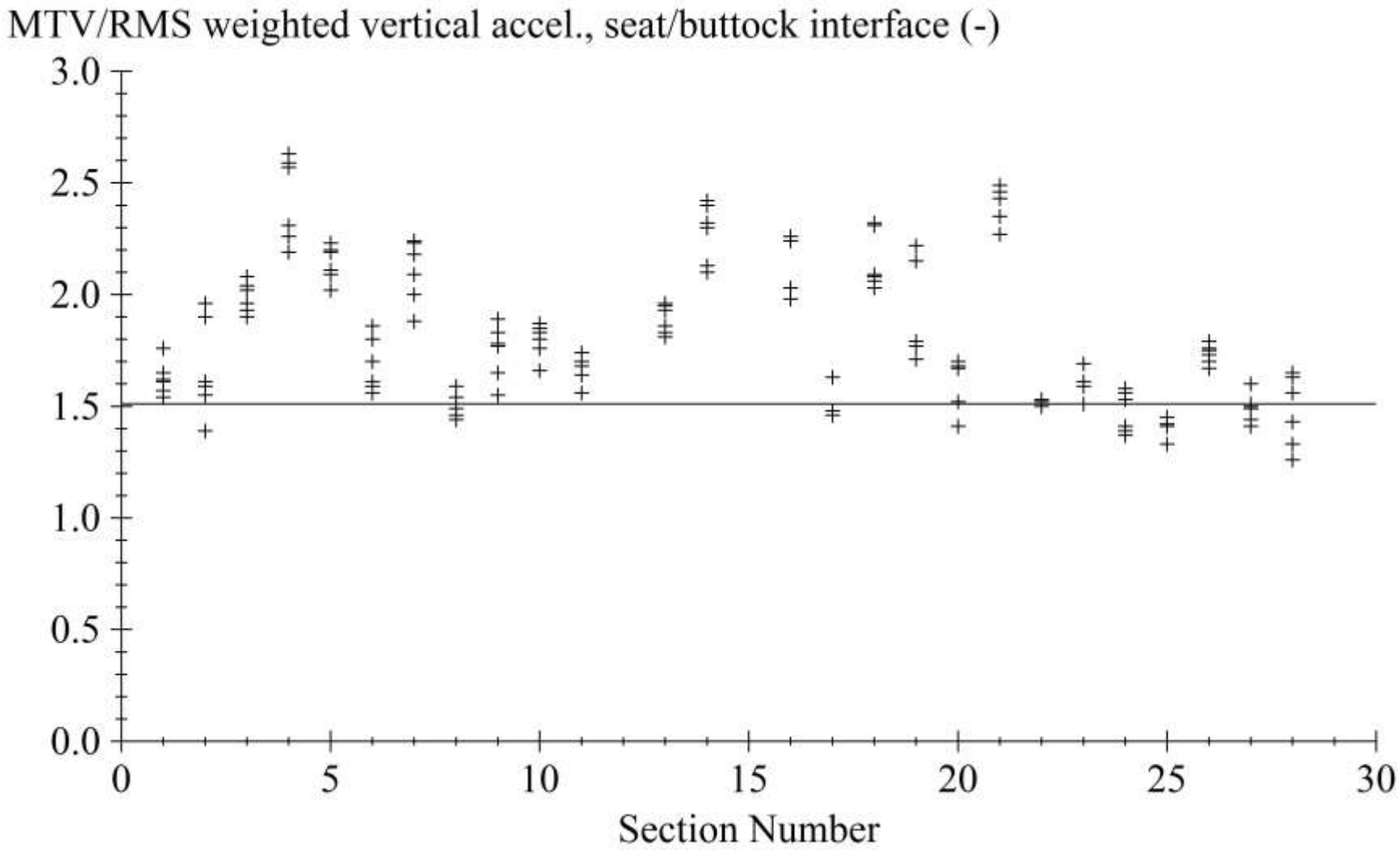
$$MTV = max\left(rmsa_{w,T}(j) \right), j = 1, N - M$$

Crest Factor: $$CF = \frac{\max\left(|a_w(j)|, j = 1, N \right)}{rmsa_w}$$

Transient vibration if: $$\frac{rmqa_w}{rmsa_w} > 1.5, \quad \frac{MTV}{rmsa_w} > 1.5, \quad CF > 9$$

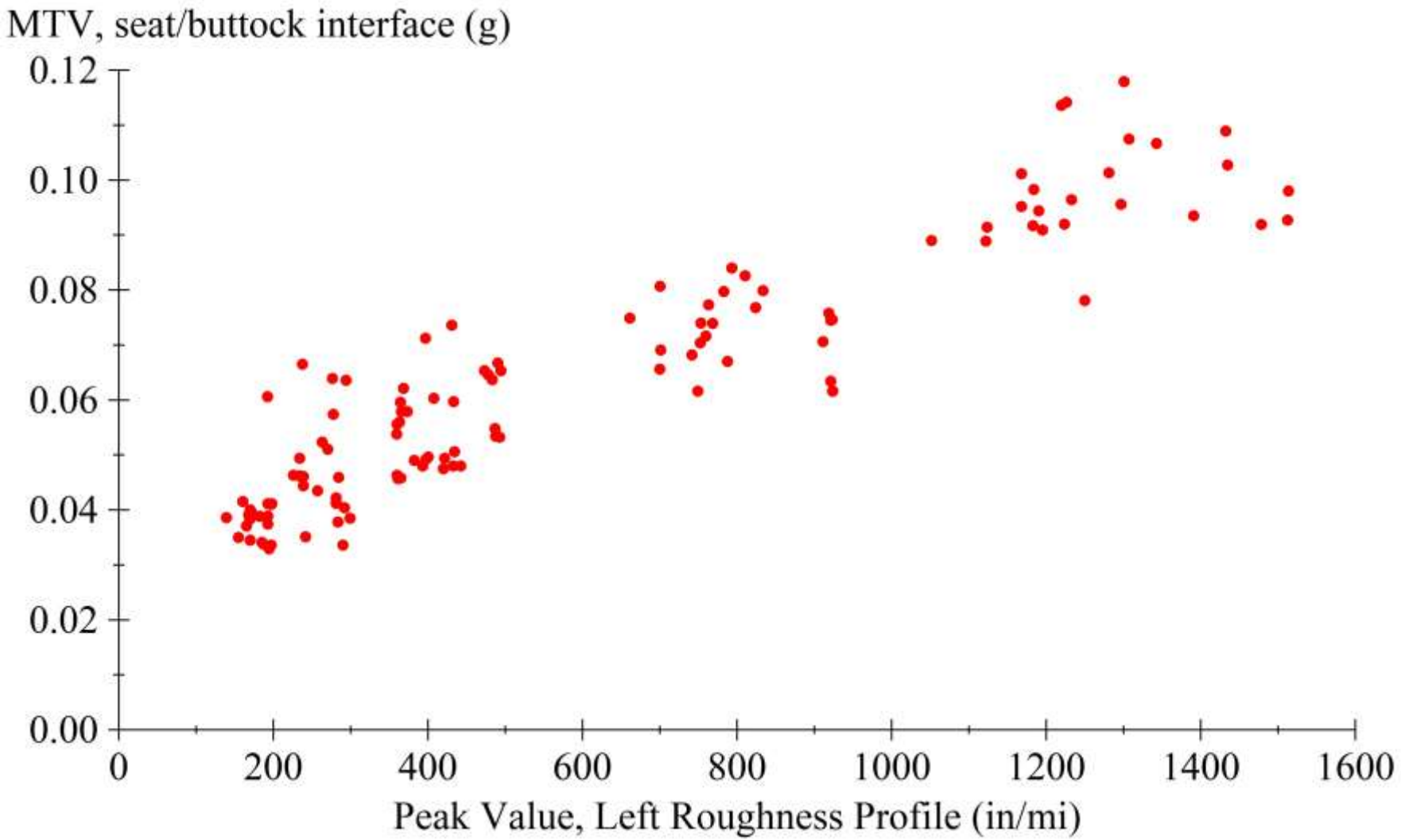
Source: ISO 2631/SAE J2834

MTV/rmsa$_w$, Mid-Sized Sedan



Source: NCHRP Rpt. 914

MTV versus Peak Localized Roughness



Source: NCHRP Rpt. 914

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Summary

- IRI correlated to measures of ride discomfort on low-speed and urban roadways, but better correlation is possible.
- A shift toward shorter wavelengths improved correlation.
- Optimizing correlation for limited conditions is not recommended.
- Localized roughness must be considered to quantify functional quality.

Discussion Points

- Can a new scale be accommodated?
- Should we avoid a scale in inches/mi?
- Should we be using a relative or absolute measure of localized roughness?
- How shall we establish new thresholds?
- What is a higher priority, functional status or pavement health?

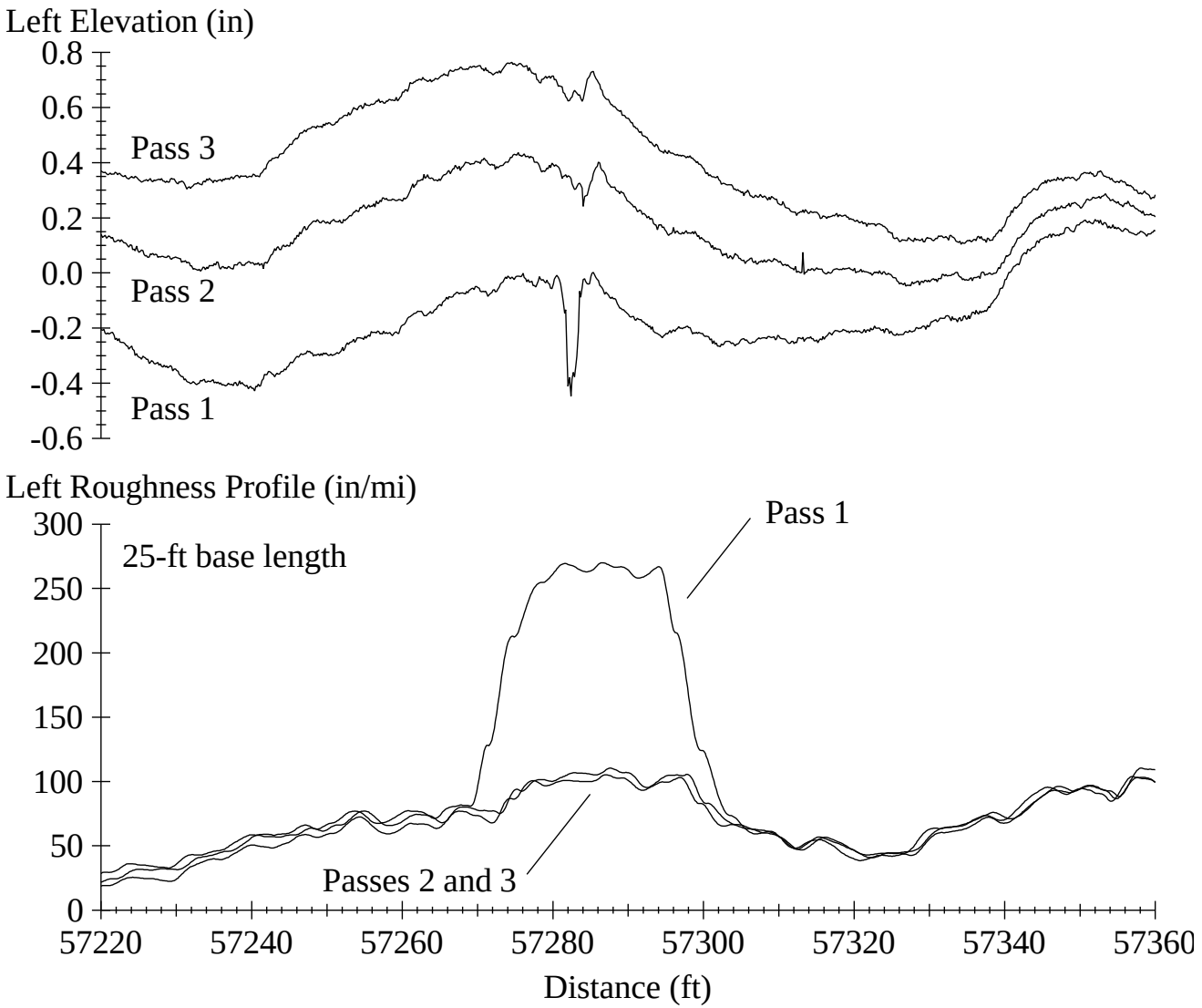
The Report……

Download NCHRP Report 914

http://www.trb.org/Publications/Blurbs/179566.aspx

Thank you!!!!

Built-In Roughness: Hit or Miss Utility Cover



Source: NCHRP Rpt. 914

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Built-In Roughness: Compound Event

Source: NCHRP Rpt. 914

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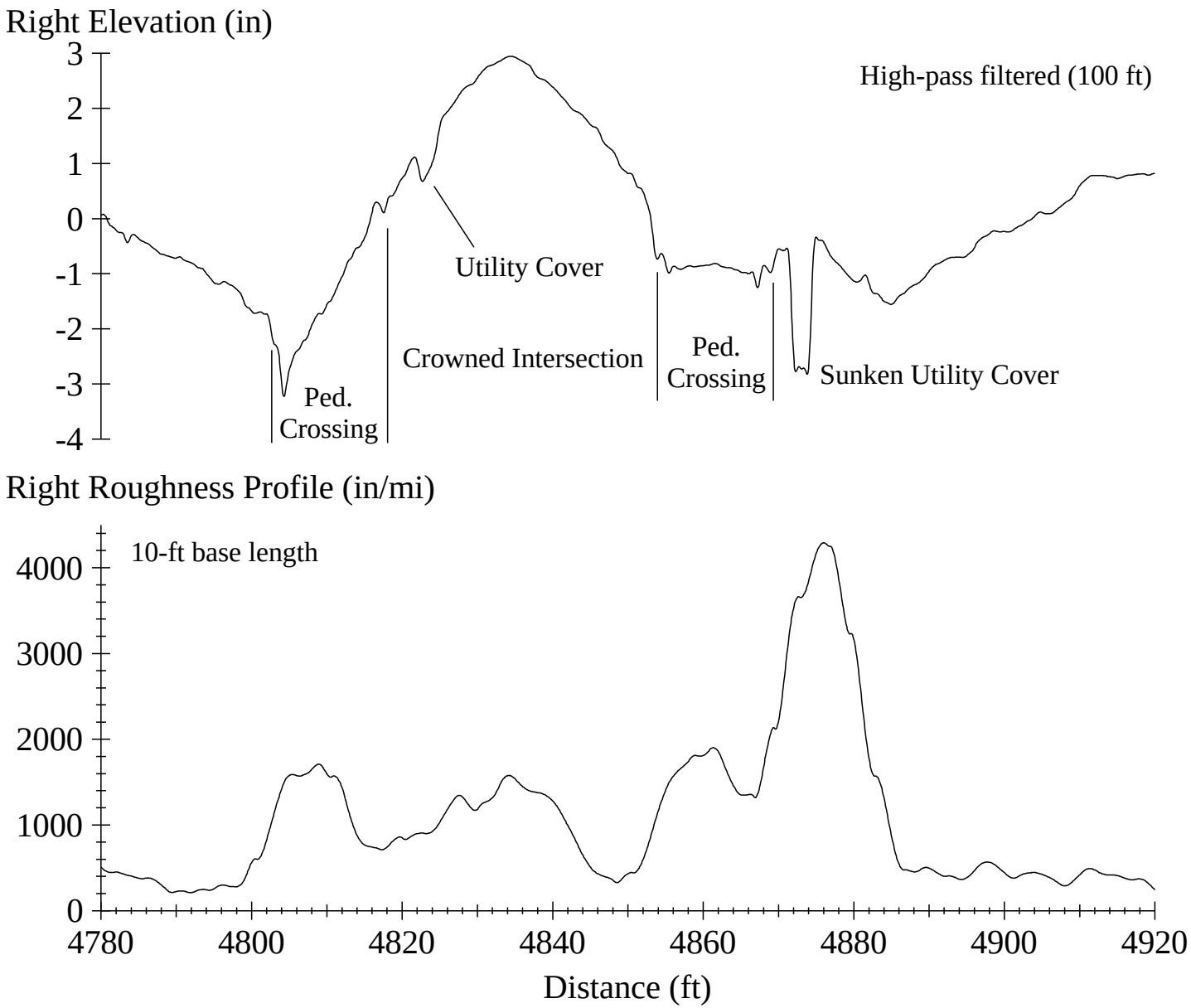
Built-In Roughness: Compound Event



Source: NCHRP Rpt. 914

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