2023 MCA Annual Conference

Profile Measurement and Interpretation

Steven M. Karamihas

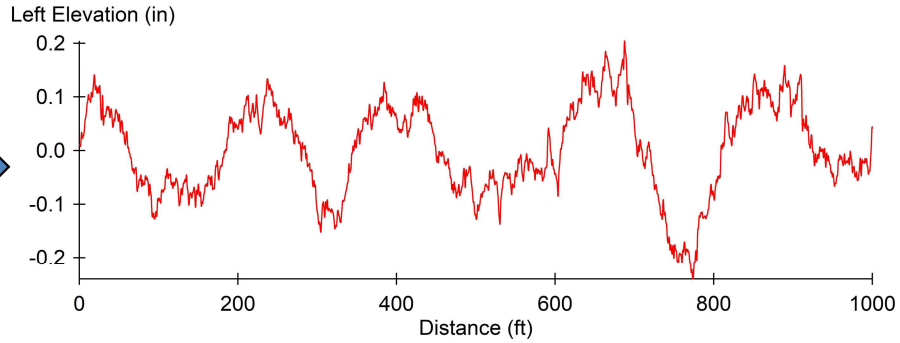
February 22, 2023

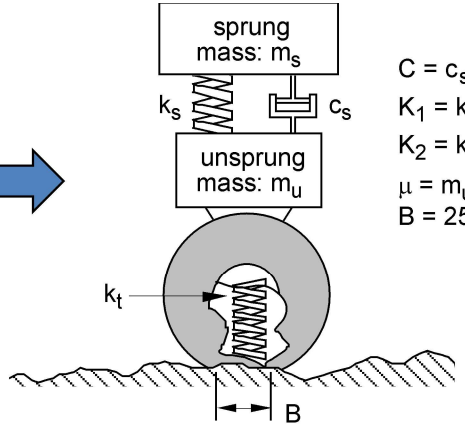
Heavy Truck Suspension Laboratory

Goals

- Provide historical and technical background
  - Inertial profilers
  - International Roughness Index (IRI)
  - Profilographs
- Identify key issues
  - Texture/Profiler footprint
  - Change in IRI with time (curl and warp)

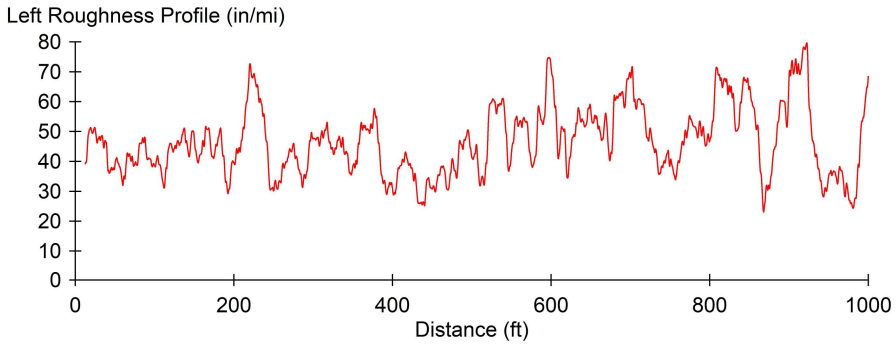
Road Profile Measurement and Interpretation



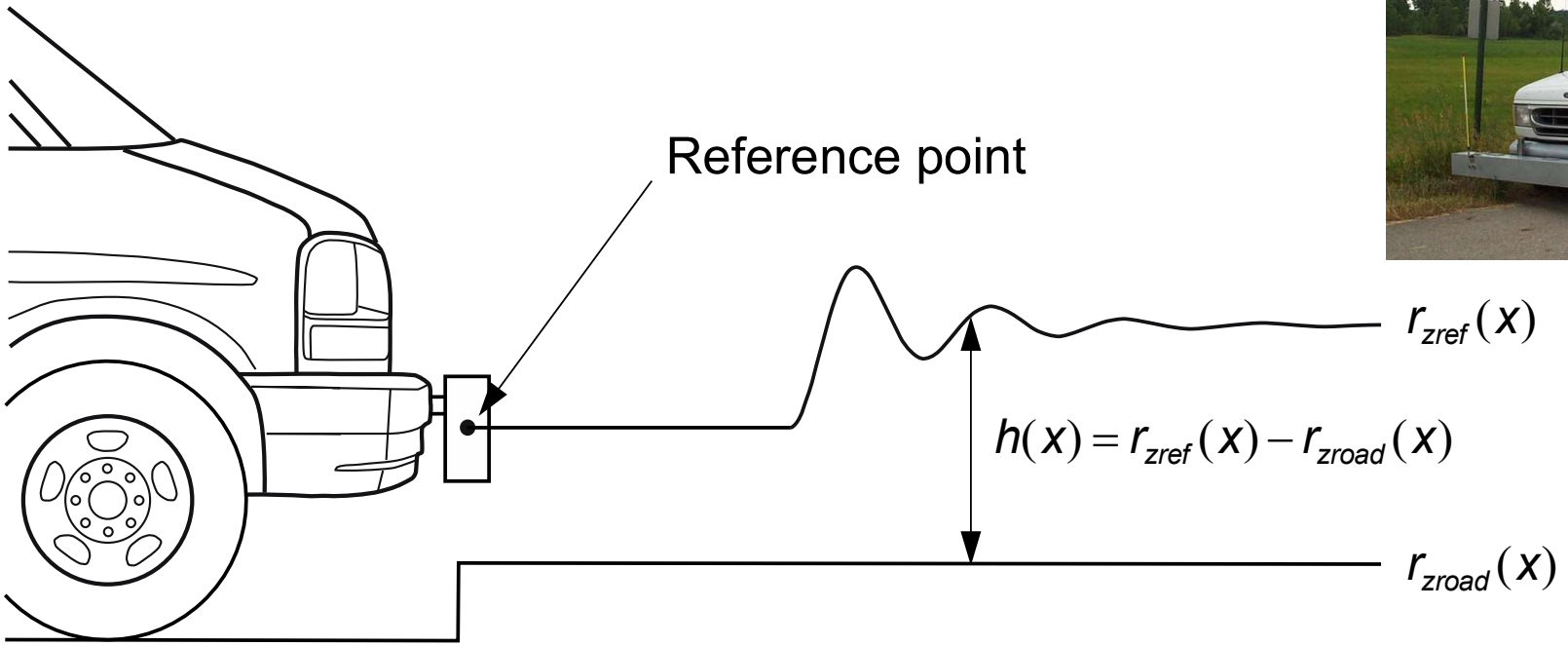


$C = c_s/m_s = 6.0\ sec^{-1}$
$K_1 = k_t/m_s = 653\ sec^{-2}$
$K_2 = k_s/m_s = 63.3\ sec^{-2}$
$\mu = m_u/m_s = 0.15$
B = 250 mm

IRI



Inertial Profiler, Principle of Operation

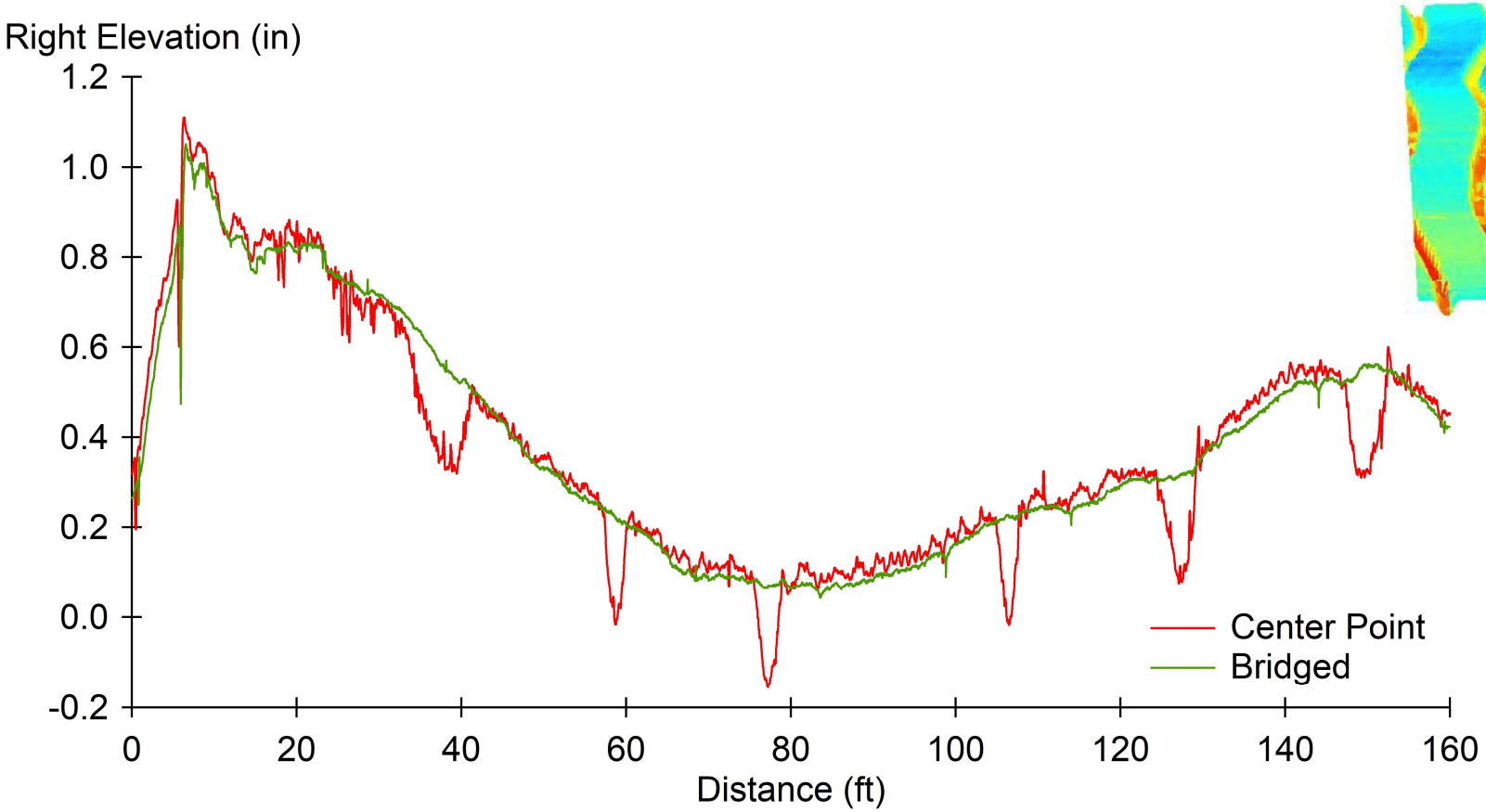


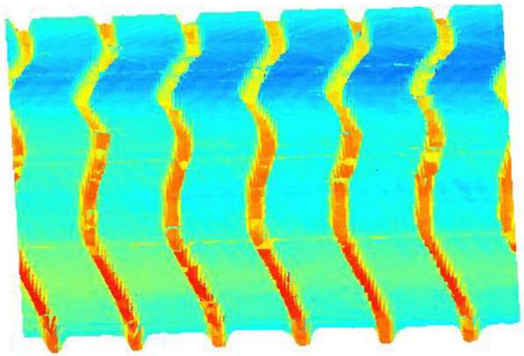
$$r_{zroad}(x) = r_{zref}(x) - \left(r_{zref}(x) - r_{zroad}(x)\right)$$

Karamihas, S.M., *Improvement of Inertial Profiler Measurements of Urban and Low-Speed Roadways*. Ph.D. Dissertation, University of Michigan (2021) 214 p.

Texture/Height Sensor Interaction

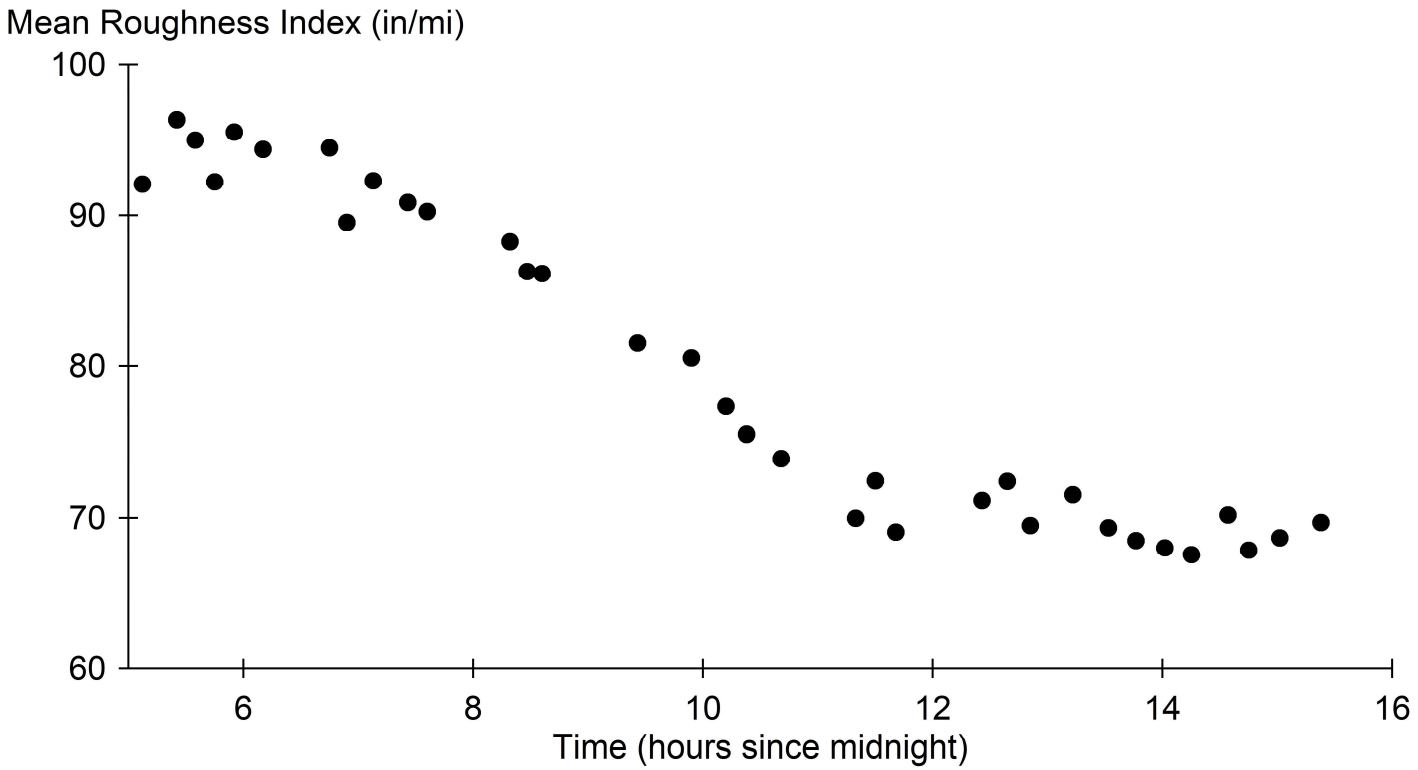
Texture/Height Sensor Interaction





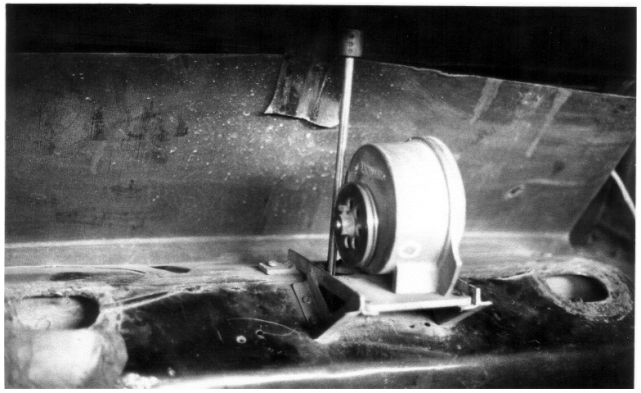
Start Here, Follow the Reference Chain: Perera, R.W. and Karamihas, S.M., "Study for Establishing Regional Certification Centers for Inertial Profilers." Federal Highway Administration (2014).

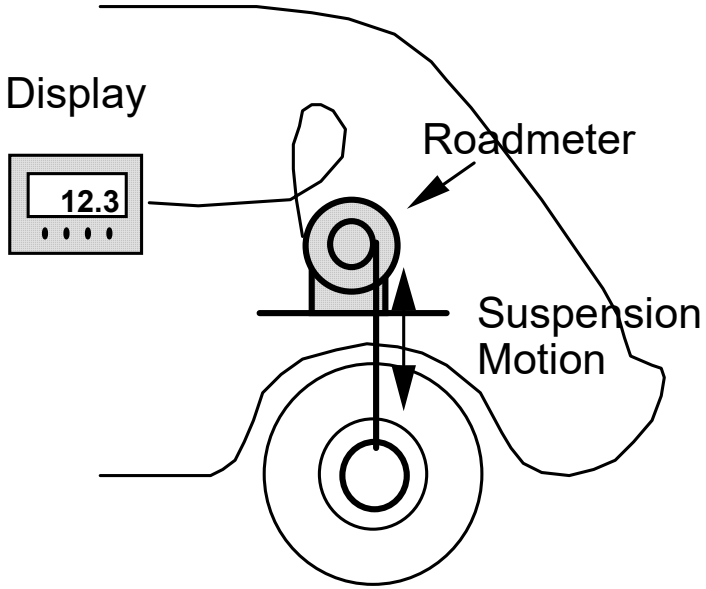
Measurement Timing (LTPP Section 260213)



Early-Age: Merritt, D.K. et al., "Evaluating the Effects of Concrete Pavement Curling and Warping on Ride Quality." *Colorado Department of Transportation Report No. CDOT-2015-07* (2015) 70 p.
Early-Age: Ceylan, H. et al., *Impact of Curling, Warping, and Other Early-Age Behavior on Concrete Pavement Smoothness: Early, Frequent, and Detailed (EFD) Study. Phase II Final Report.* Report No. FHWA DTFH61-01-X-00042, Federal Highway Administration (2007).
Plot Source: Karamihas, S. M., Perera, R. W., Gillespie, T. D. and Kohn, S. D., "Diurnal Changes in Profile of Eleven Jointed PCC Pavements." *7th International Conference on Concrete Pavements. Proceedings. Volume 1,* (2001) pp. 69-80.

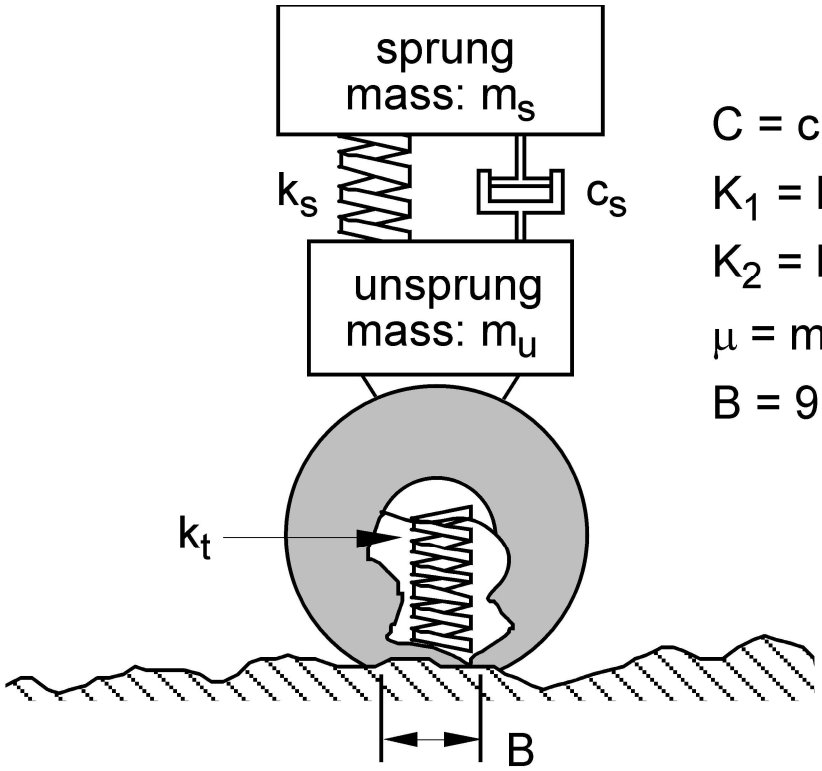
IRI Origins: Response-Type Systems





Photos Courtesy of Mike Sayers
Schematic: Gillespie, T.D., "Everything You Always Wanted to Know about the IRI, But Were Afraid to Ask!" 1992 Road Profiler Users' Group Meeting, Lincoln, NE.

Golden-Car Model/IRI



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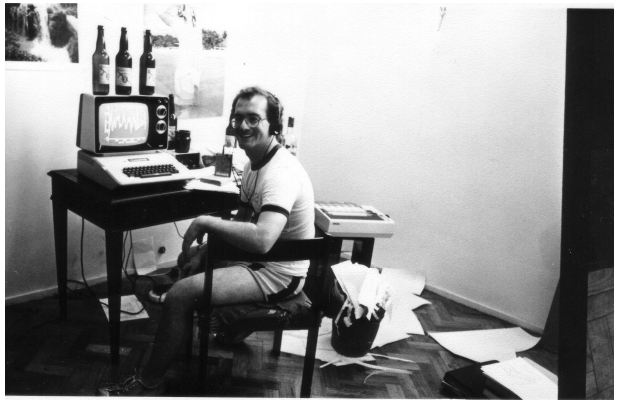
$K_2 = k_s/m_s = 63.3\ sec^{-2}$

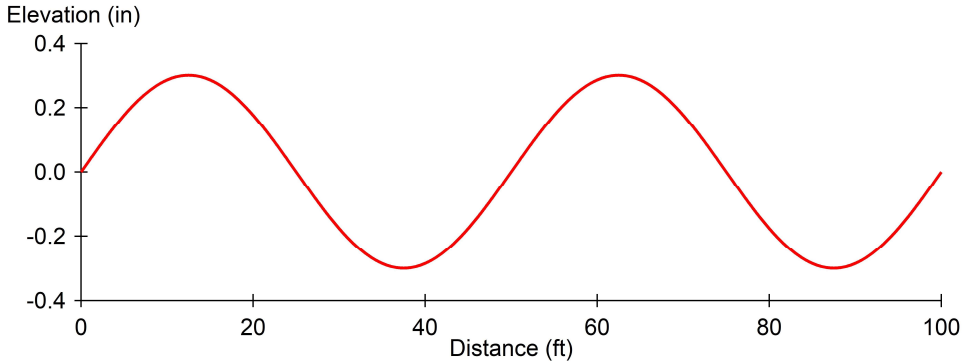
$\mu = m_u/m_s = 0.15$

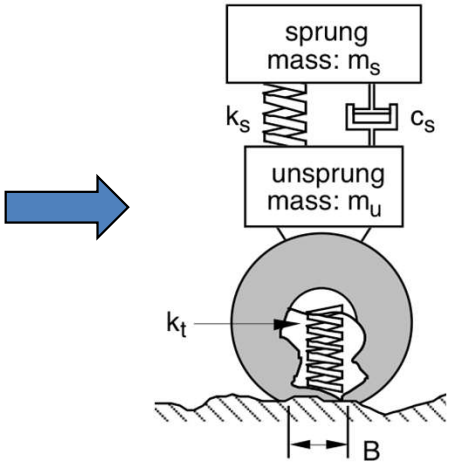
$B = 9.84\ in$



Sayers, M.W., "On the Calculation of International Roughness Index from Longitudinal Road Profile." *Transportation Research Record 1501* (1995) pp. 1-12.
Background: NCHRP Report 228
Background: World Bank Technical Papers 45 and 46.

Sine Waves (50-ft and 6.7-ft wavelengths)





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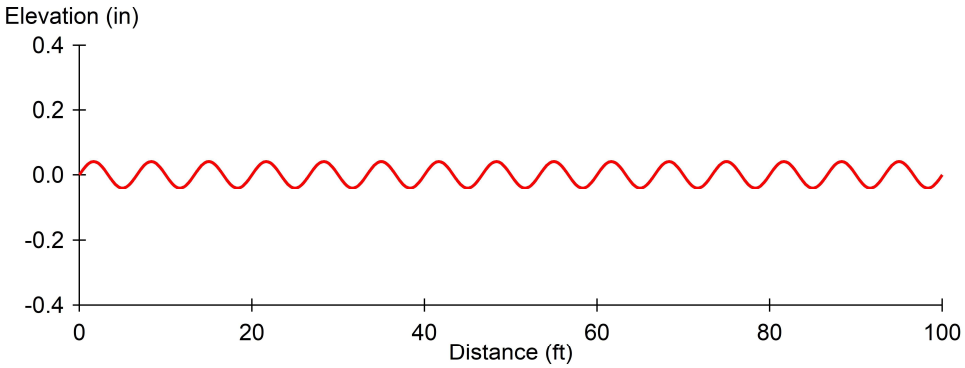

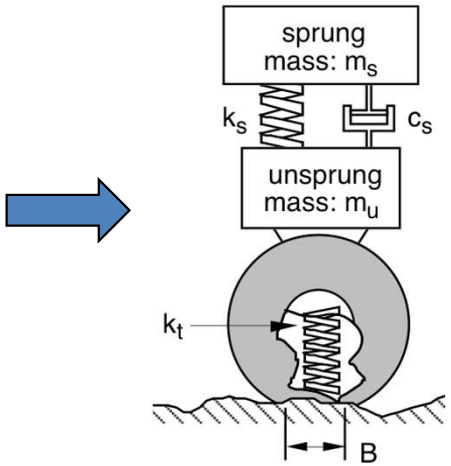

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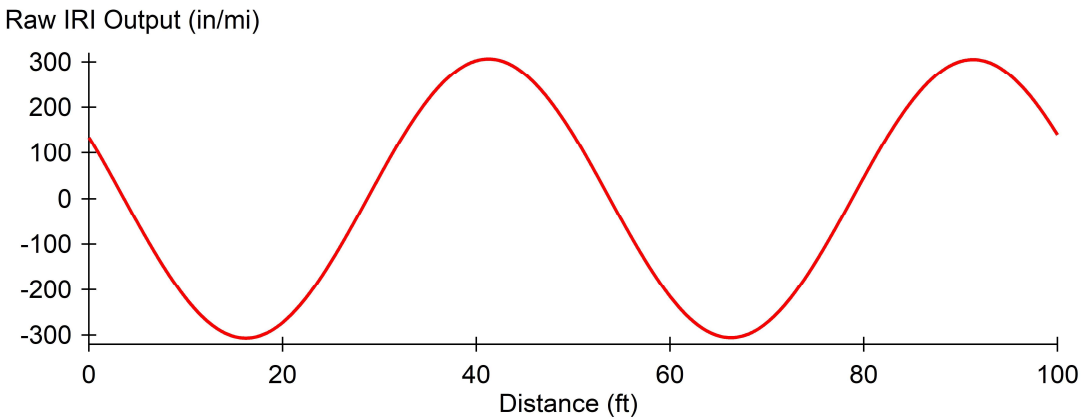
Sine Wave Stats, 49.7 mi/hr Speed

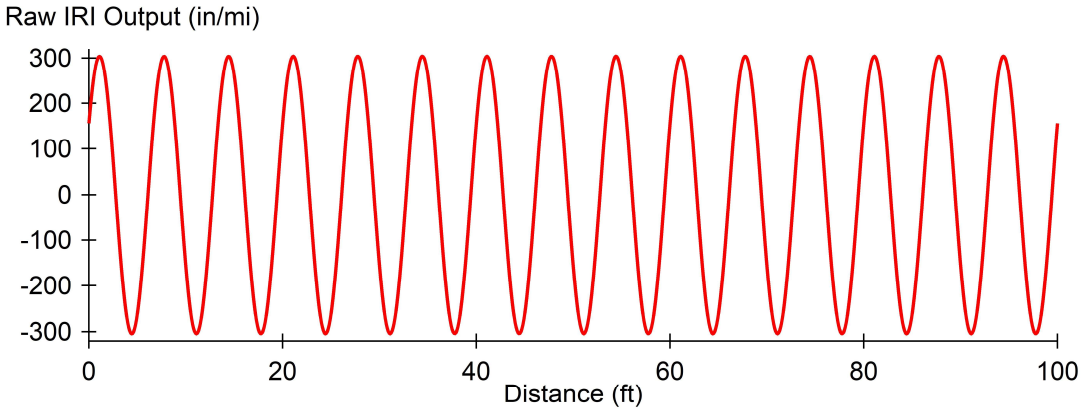
Wavelength:	50 ft	Wavelength:	6.67 ft
AMPLITUDES:		AMPLITUDES:	
Elevation:	0.3 in	Elevation:	0.04 in
Slope:	199 in/mi	Slope:	199 in/mi
AMPLITUDES AT 49.7 mi/hr:		AMPLITUDES AT 49.7 mi/hr:	
Velocity:	0.229 ft/s	Velocity:	0.229 ft/s
Acceleration:	0.065 g	Acceleration:	0.49 g
Frequency:	1.46 Hz	Frequency:	10.94 Hz

Golden-Car Response to Sine Waves



INPUT:
- Wavelength: 50 ft
- Amplitude: 0.3 in

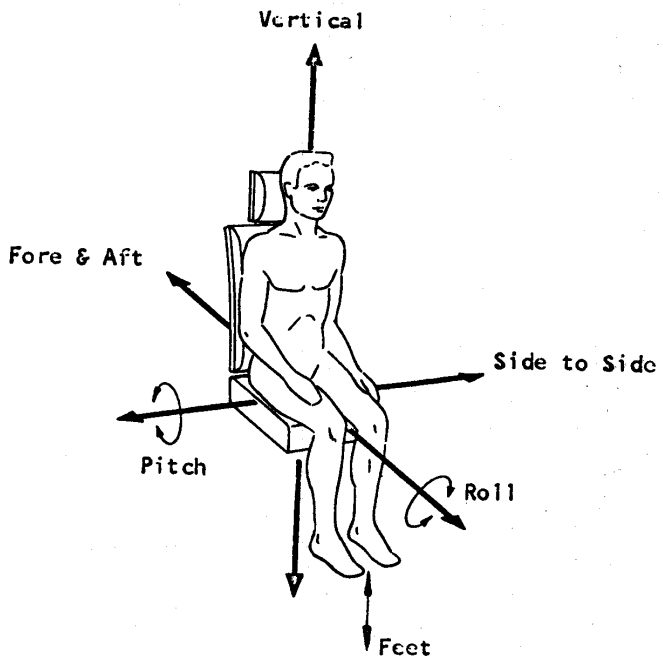
OUTPUT AMPLITUDE:
- Raw IRI: 306.3 in/mi
- (IRI = 195.0 in/mi)
- Body Acceleration: 0.099 g

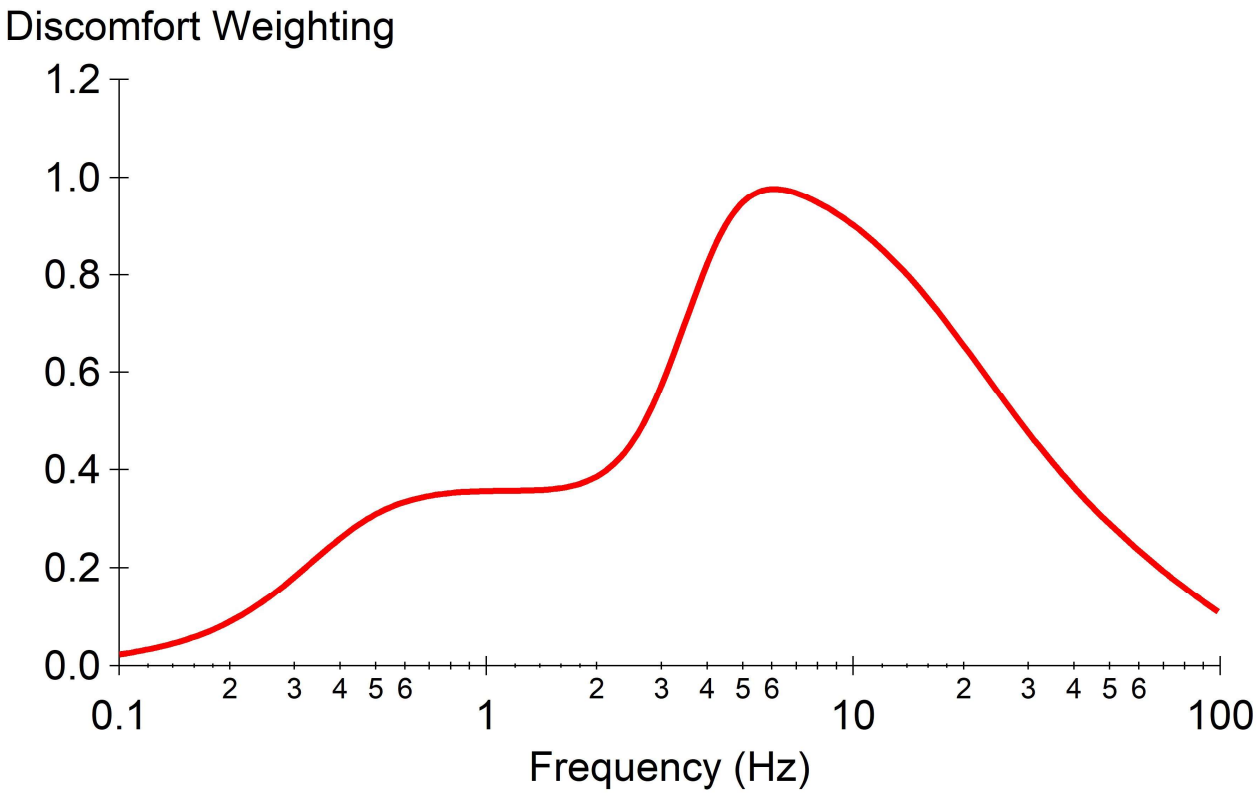


INPUT:
- Wavelength: 6.67 ft
- Amplitude: 0.04 in

OUTPUT:
- Raw IRI: 307.4 in/mi
- (IRI = 195.7 in/mi)
- Body Acceleration: 0.067 g

Human Response to Vibration

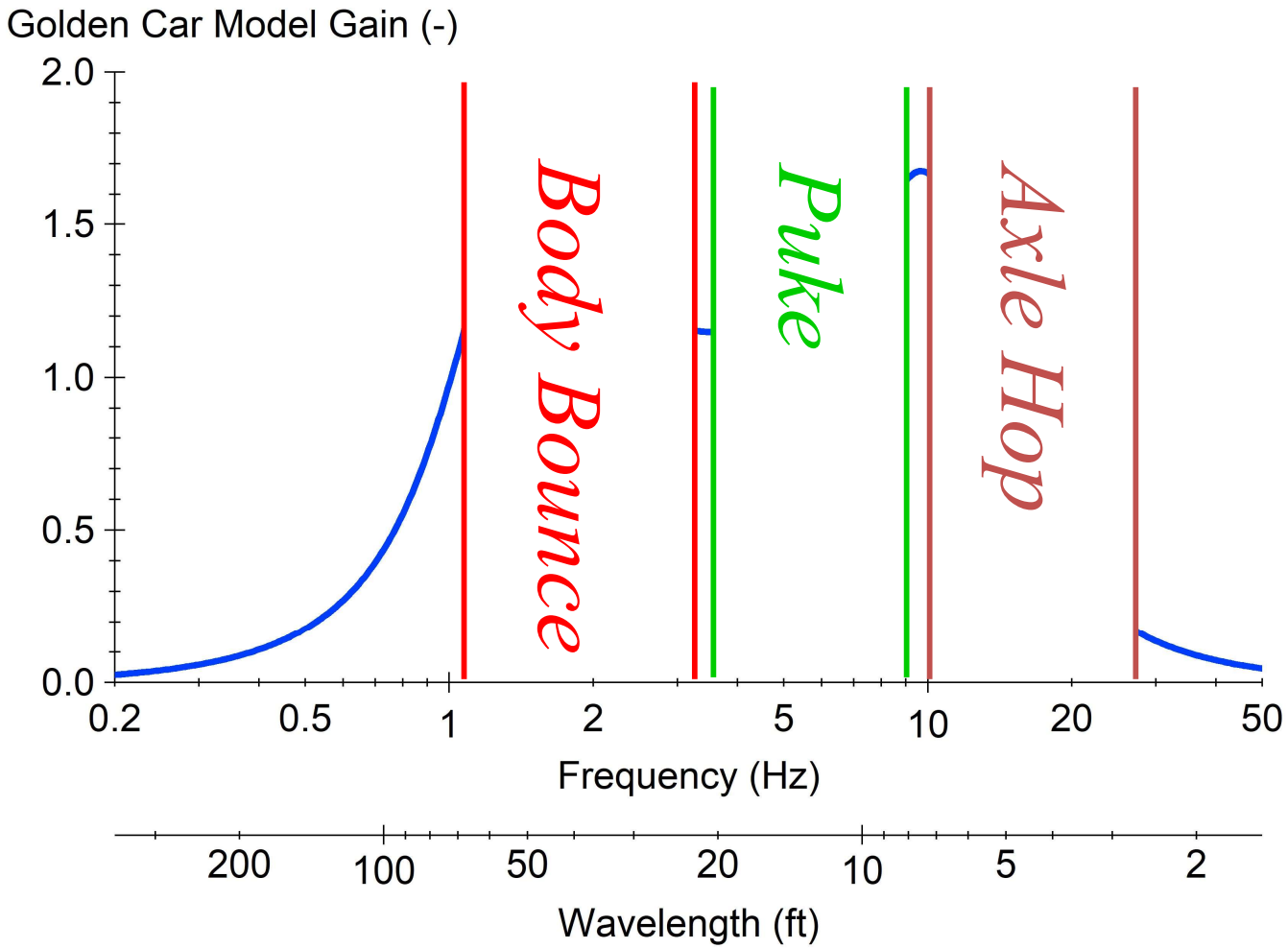




See ISO 2631: Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration.

Vehicle Response to Vibration

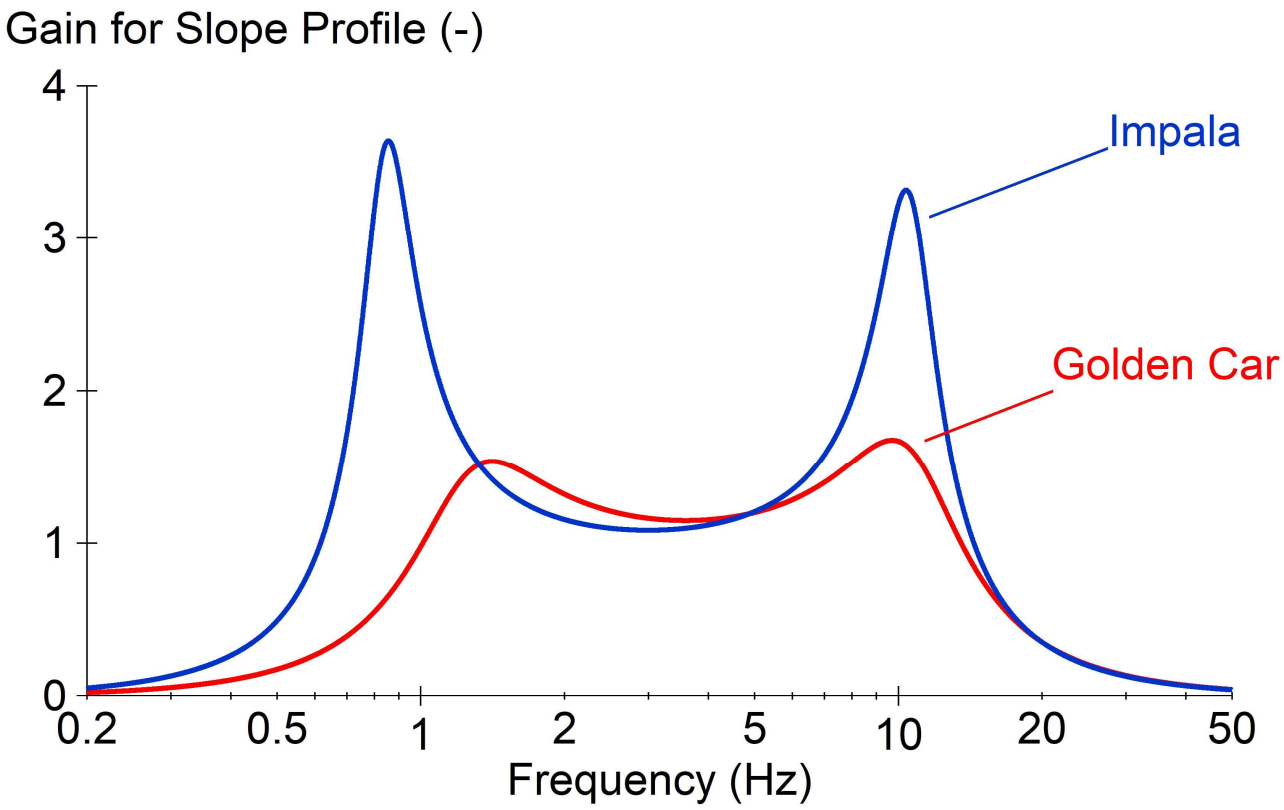
Golden Car Model Gain



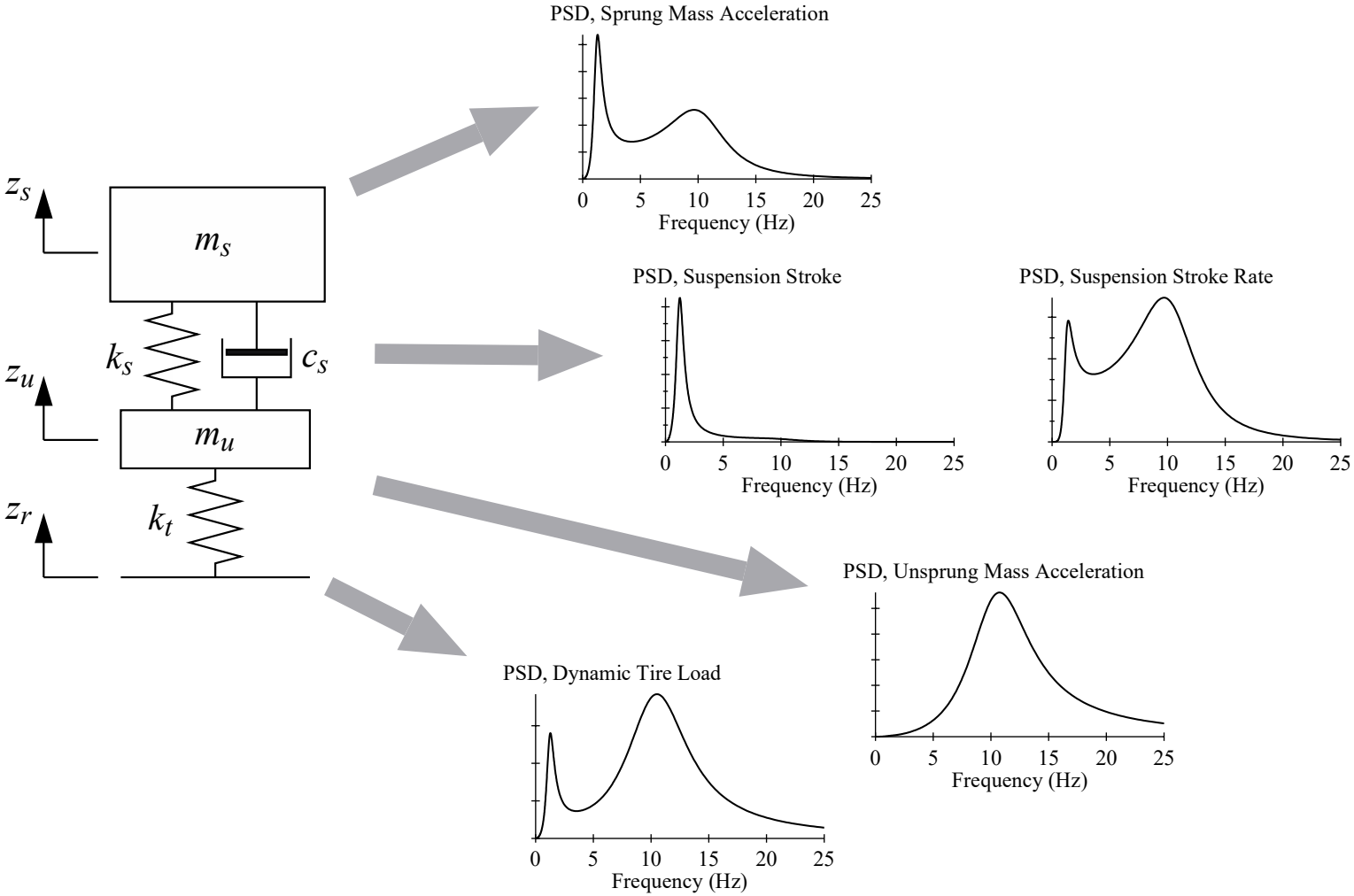
Source: National Cooperative Highway Research Program Report 914.

IRI Generality: Vehicle Type

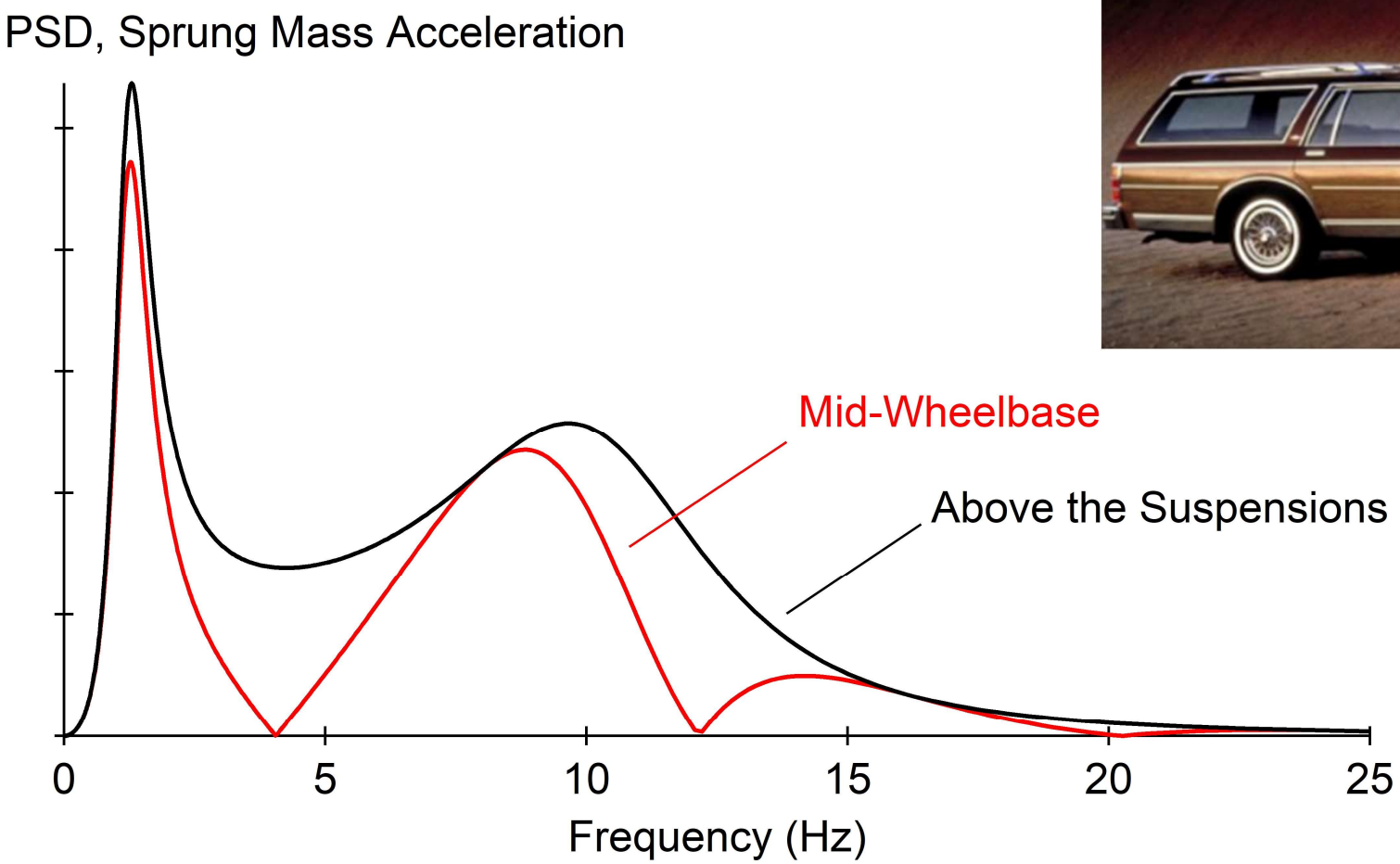
Specific vehicles will "tune in" to particular frequencies.



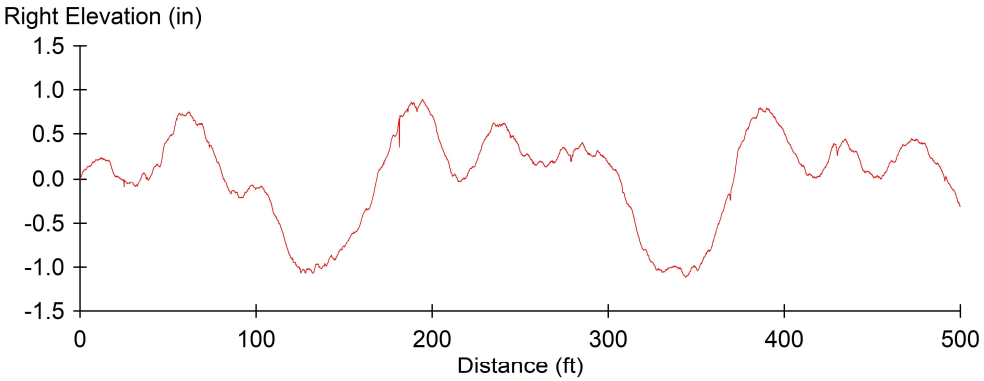
IRI Generality: Response Type

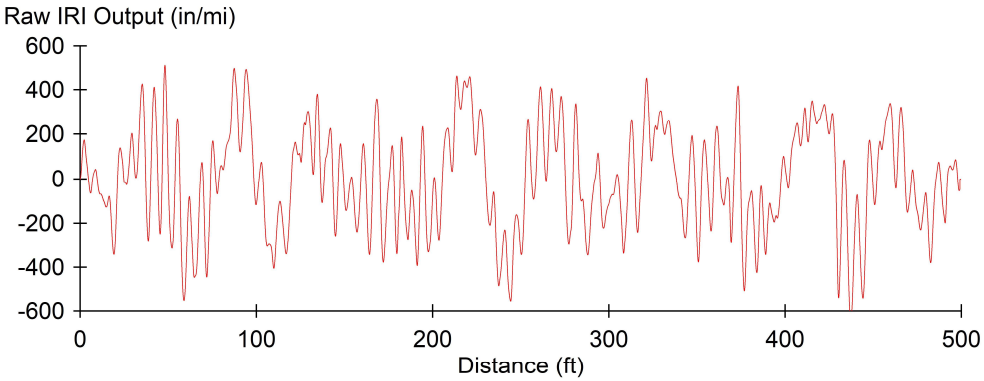


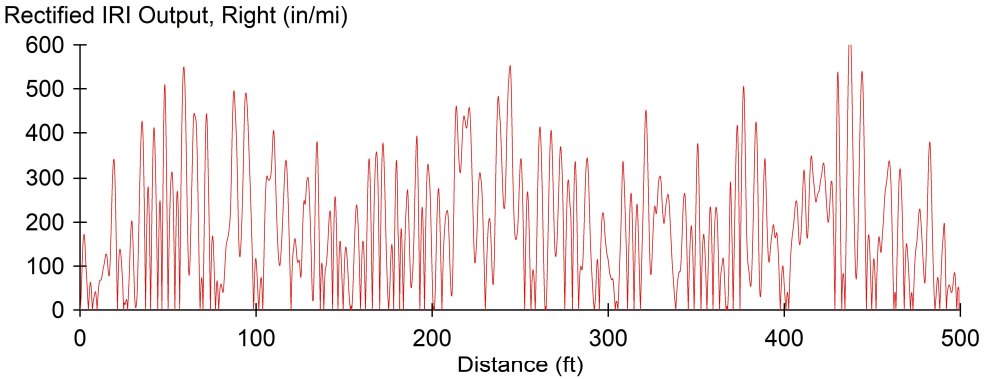
IRI Generality: Position Within the Vehicle



IRI Calculation

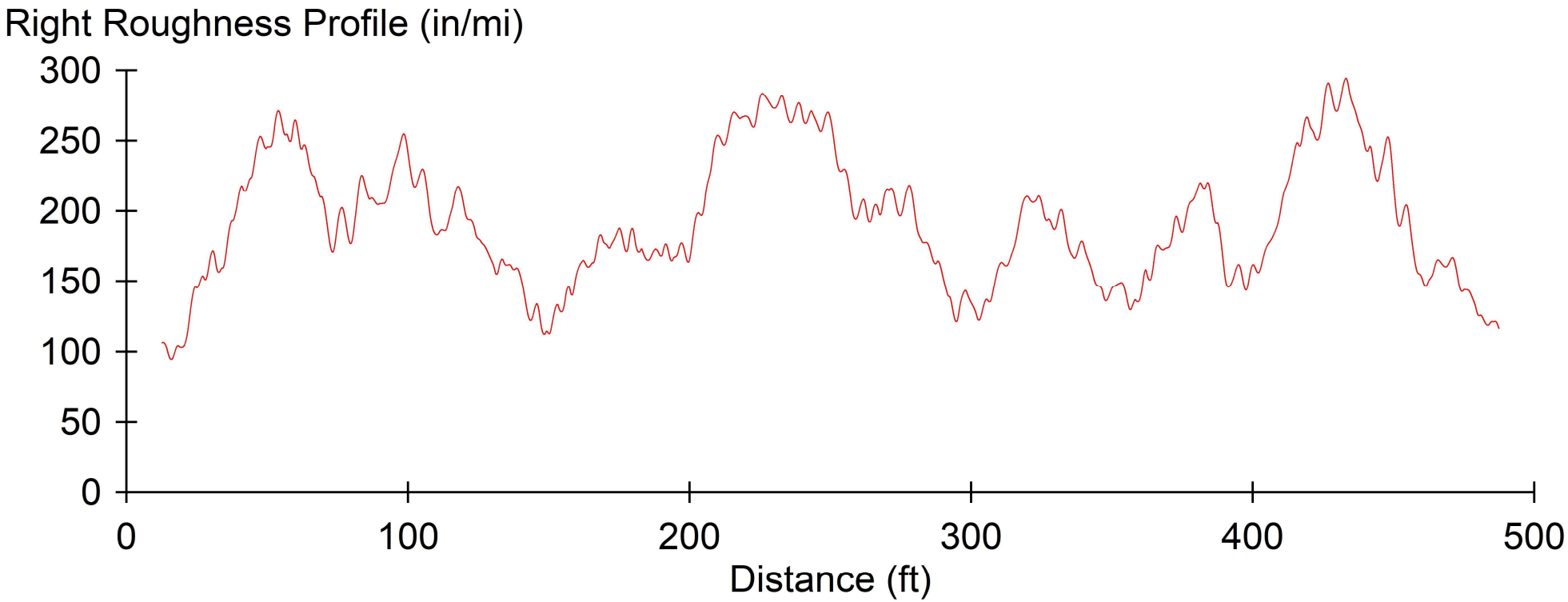




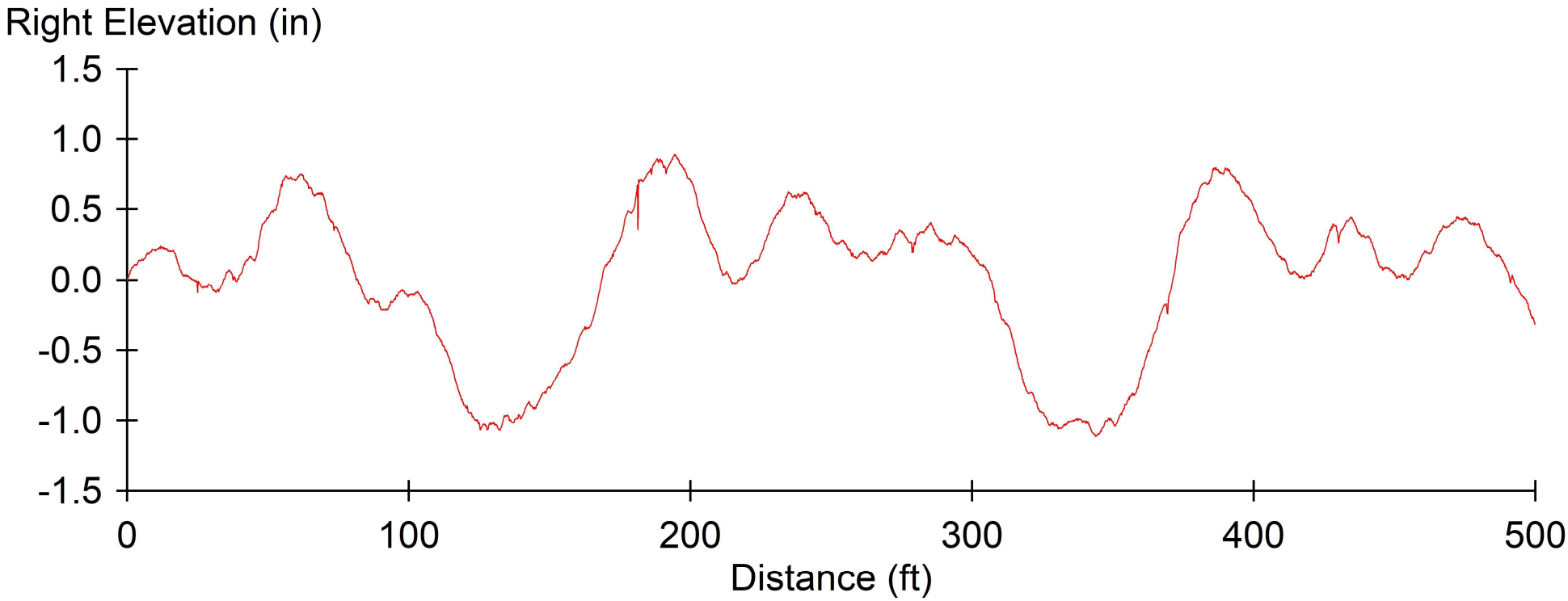


IRI =187 in/mi

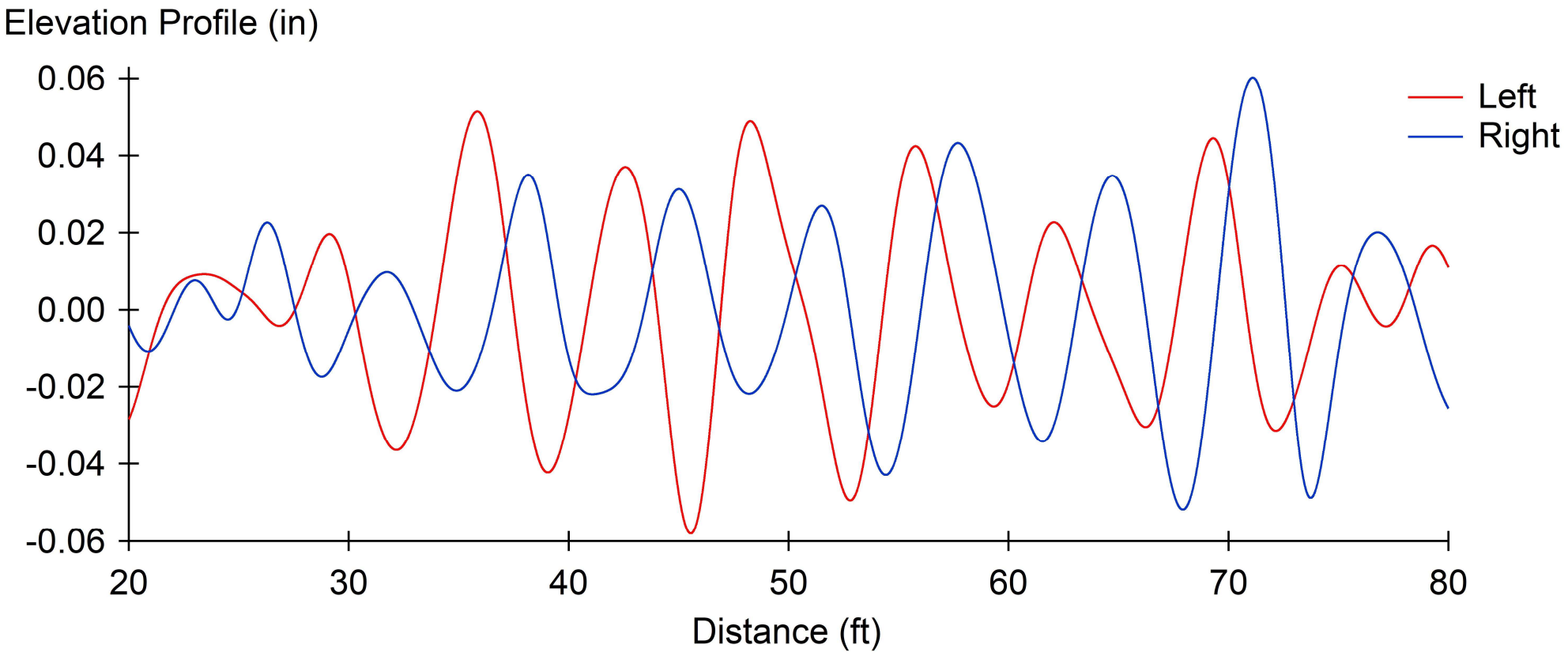
Short-Interval Roughness Profile…



…Corresponding Profile



Filtered Profile Plot (4-10 ft)



Power Spectral Density

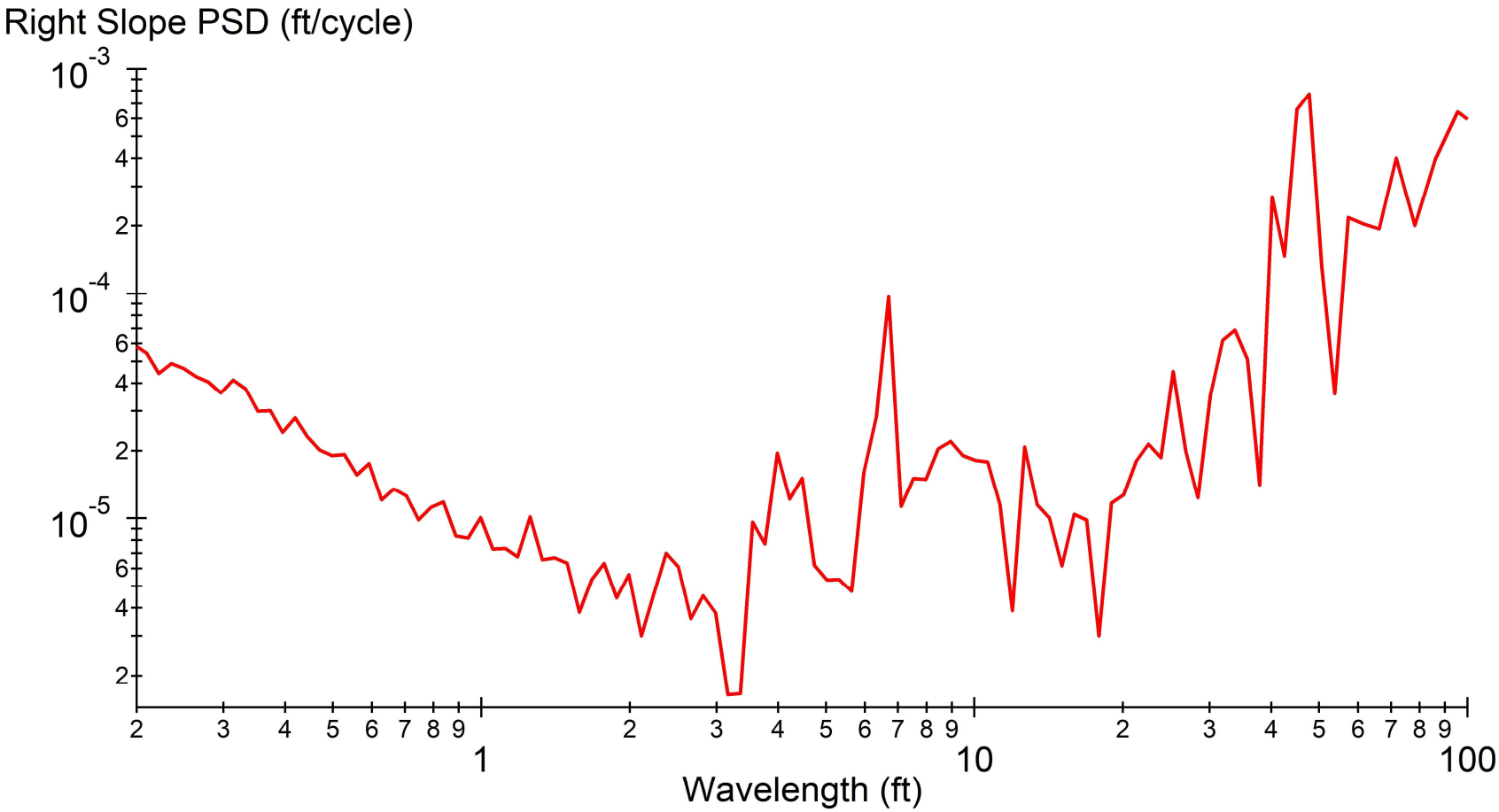
Definition from signal processing books:

> "The Fourier transform of the autocorrelation function." (Ugh!)

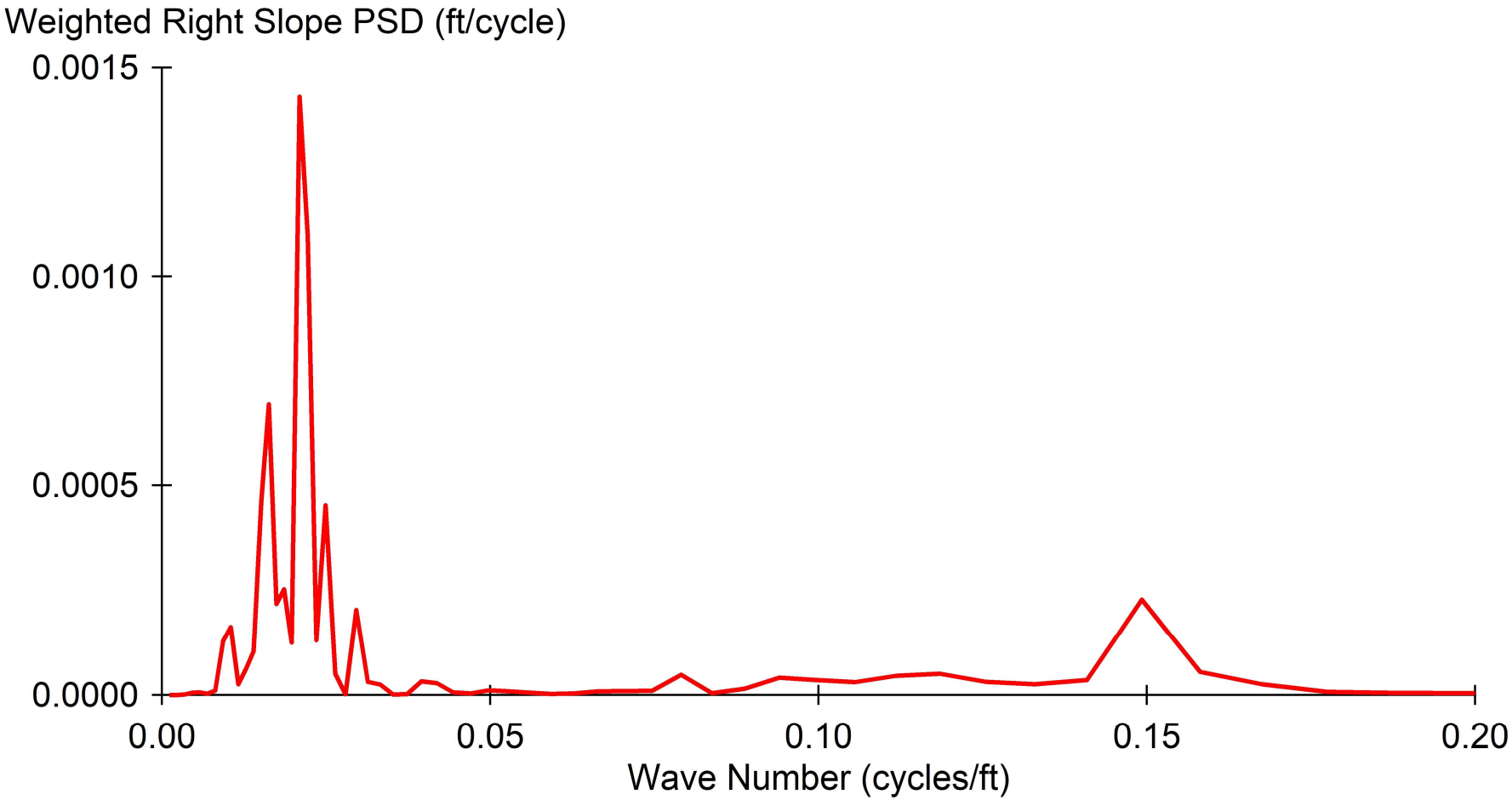
Key points:

1. In profiling, it has nothing to do with power.
   ("historical origin and use in communications…")
2. When you see it, the process started by breaking the signal down into a sum of sine waves. (Fourier transform)
3. The actual plot is re-scaled to show how variance is distributed over different frequencies. (Ugh!)
4. It helps you identify sources of roughness by wavelength.

Power Spectral Density



Weighted Power Spectral Density



Stringline

Cable, J.K., Karamihas, S.M., Brenner, M., Leichty, M., Tabbert, T., and Williams, J., “Measuring Pavement Profile at the Slip-Form Paver.” Iowa State University, *IHRB Project TR-512* (2005) 50 p.
Also, search on: Real-Time Smoothness and Dave Merritt.

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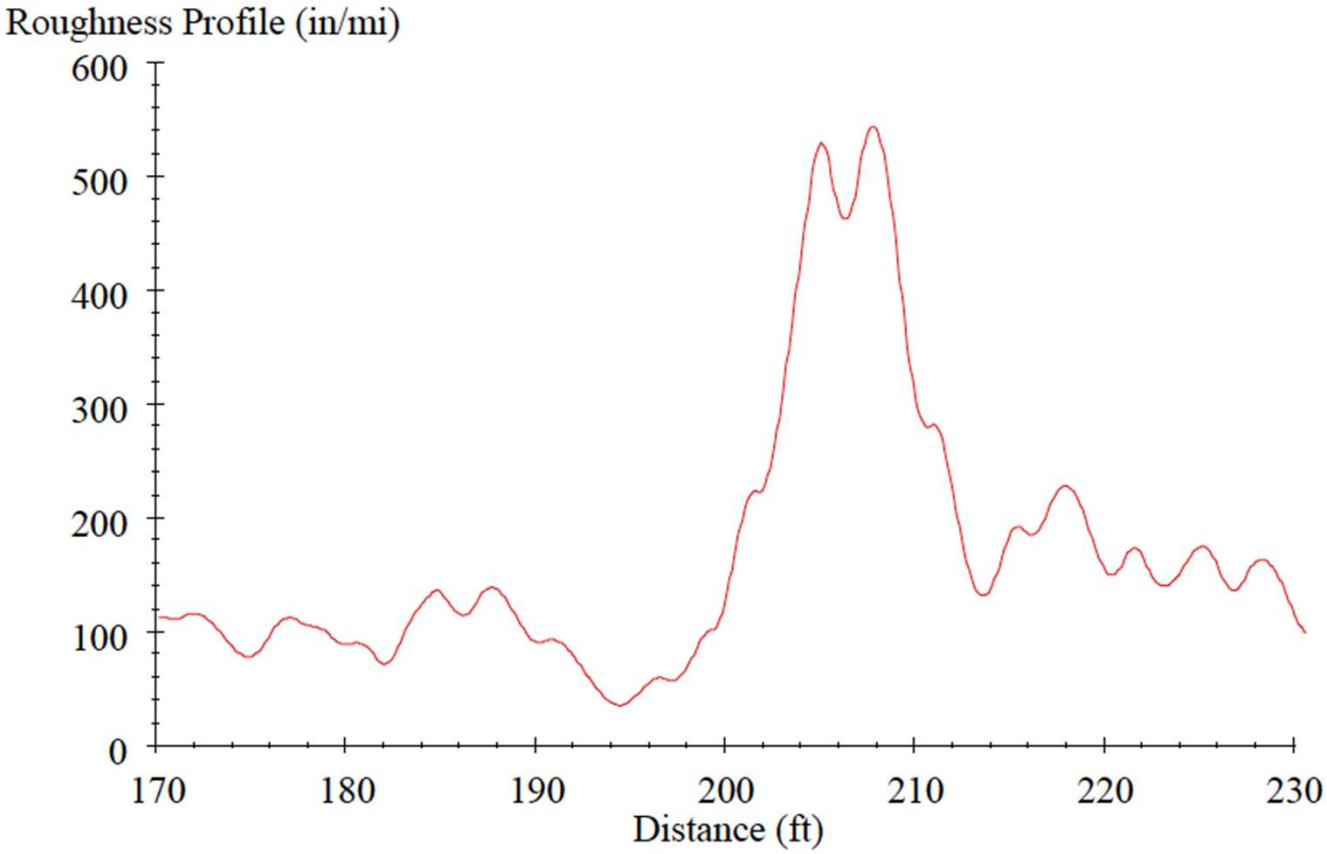

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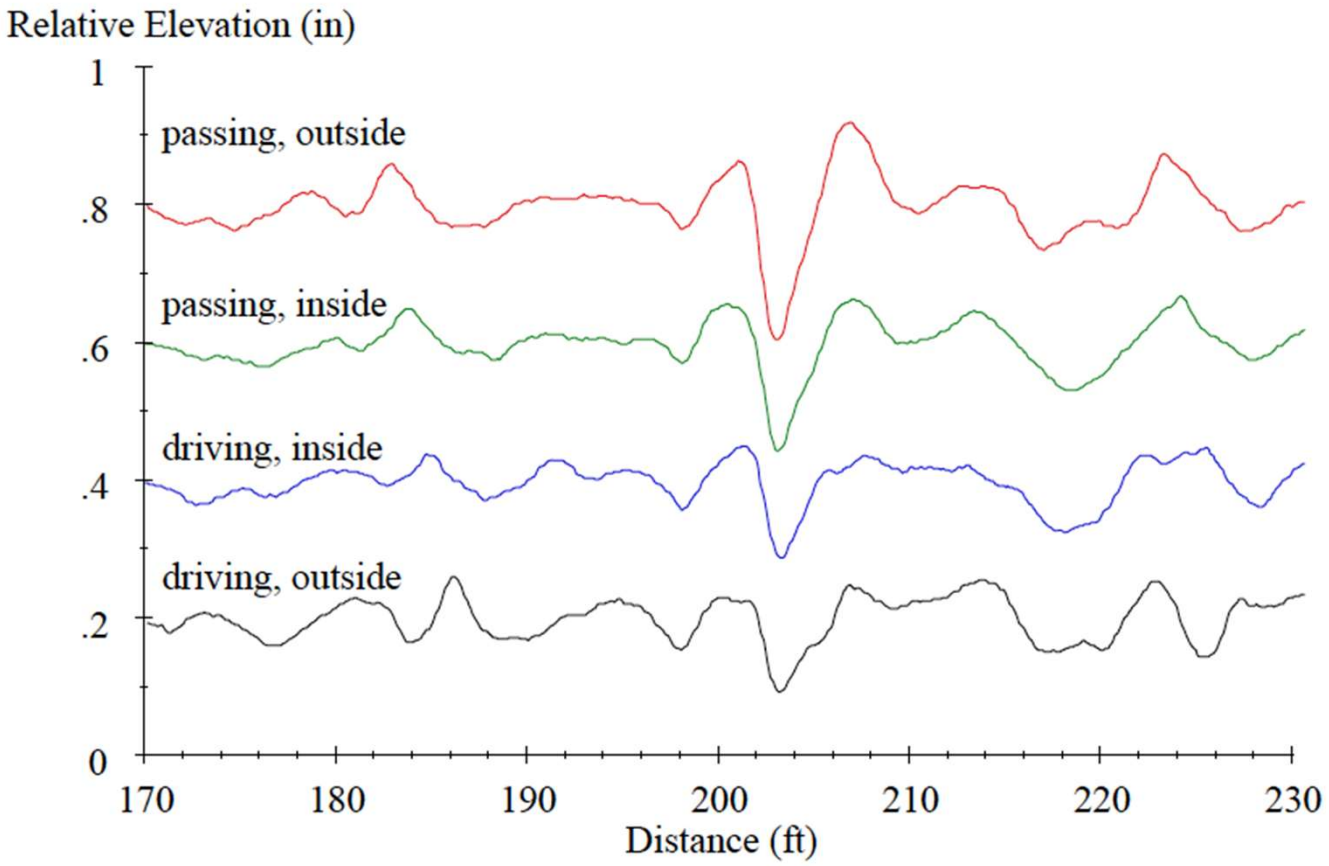

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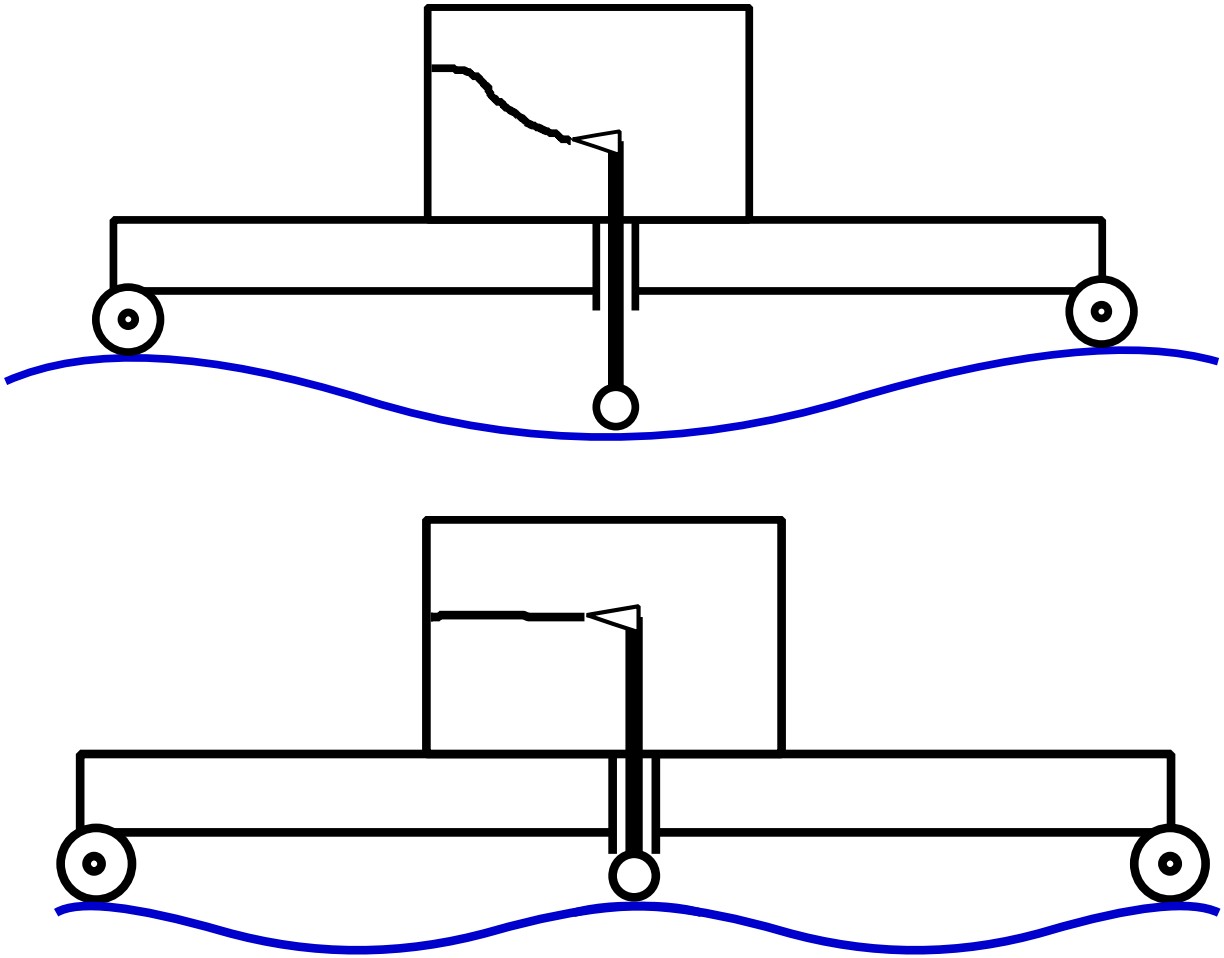
Also, search on: Real-Time Smoothness and Dave Merritt.

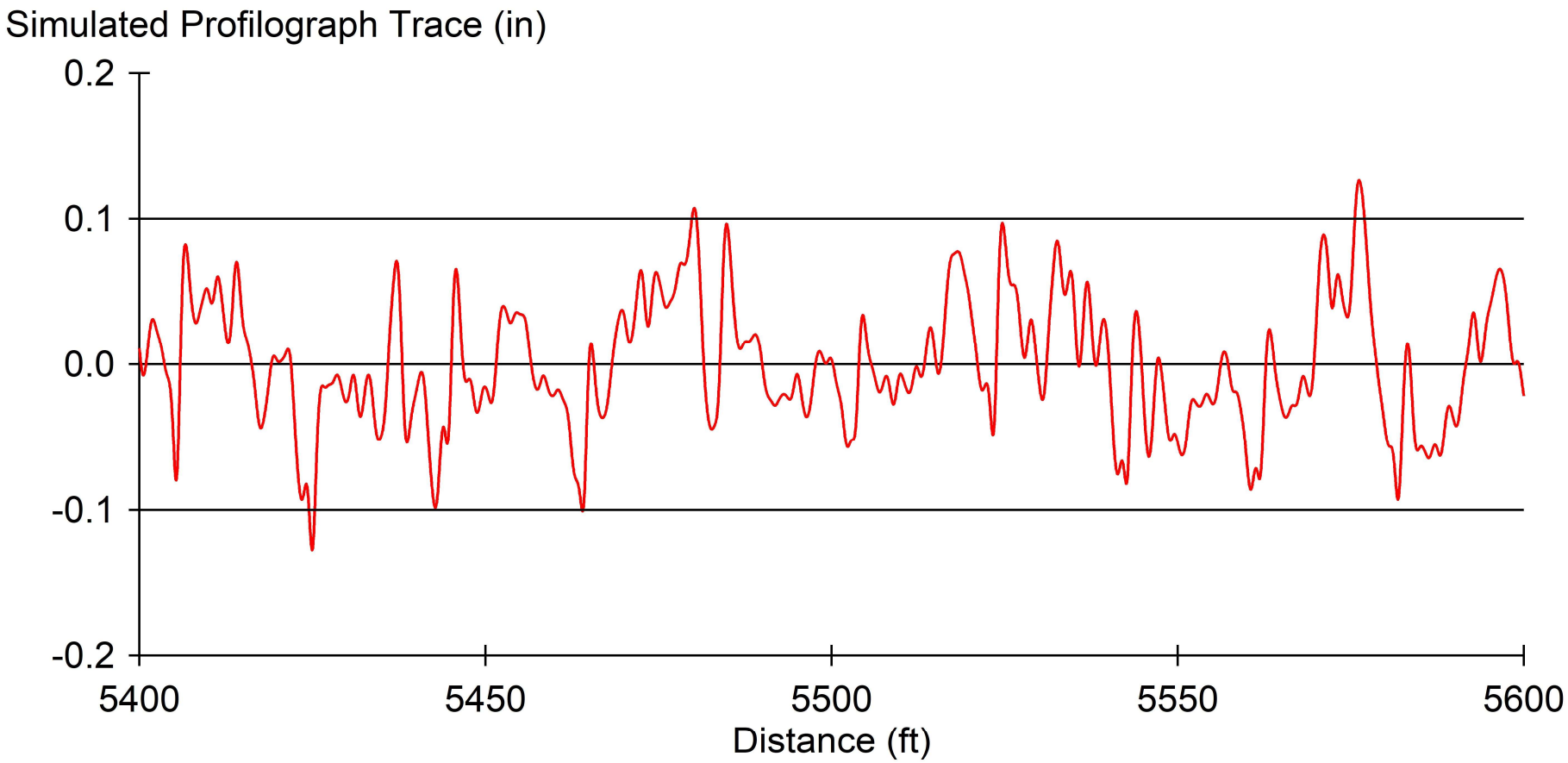
Profilographs

Photo from: Karamihas, S.M. and Gillespie, T.D., “Assessment of Profiler Performance for Construction Quality Control: Phase I.” *PCA R&D Serial No. 2877* (2005) p. 55.

Straightedge Response



Simulated Profilograph Trace: Autofloat Problem



Key Issues

Addressed here:

- IRI represents general vehicle response.
- Profilographs represent vehicle response much less directly.
- Use an appropriate height sensor footprint on coarse texture.
- Be aware of cyclic changes in roughness.
- Use roughness profiles, filtered profile plots, and PSD plots to help with quality control.

Not addressed:

- Roughness thresholds. (How smooth is smooth enough?)
- Profiler certification.
- Stop-and-go profiler operation.
- Traffic speed. (Low-speed index?)

Thanks!

Profile Analysis: ProVal

The Little Book of Profiling

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