Vehicle Dynamics and Simulation

Ride Dynamics

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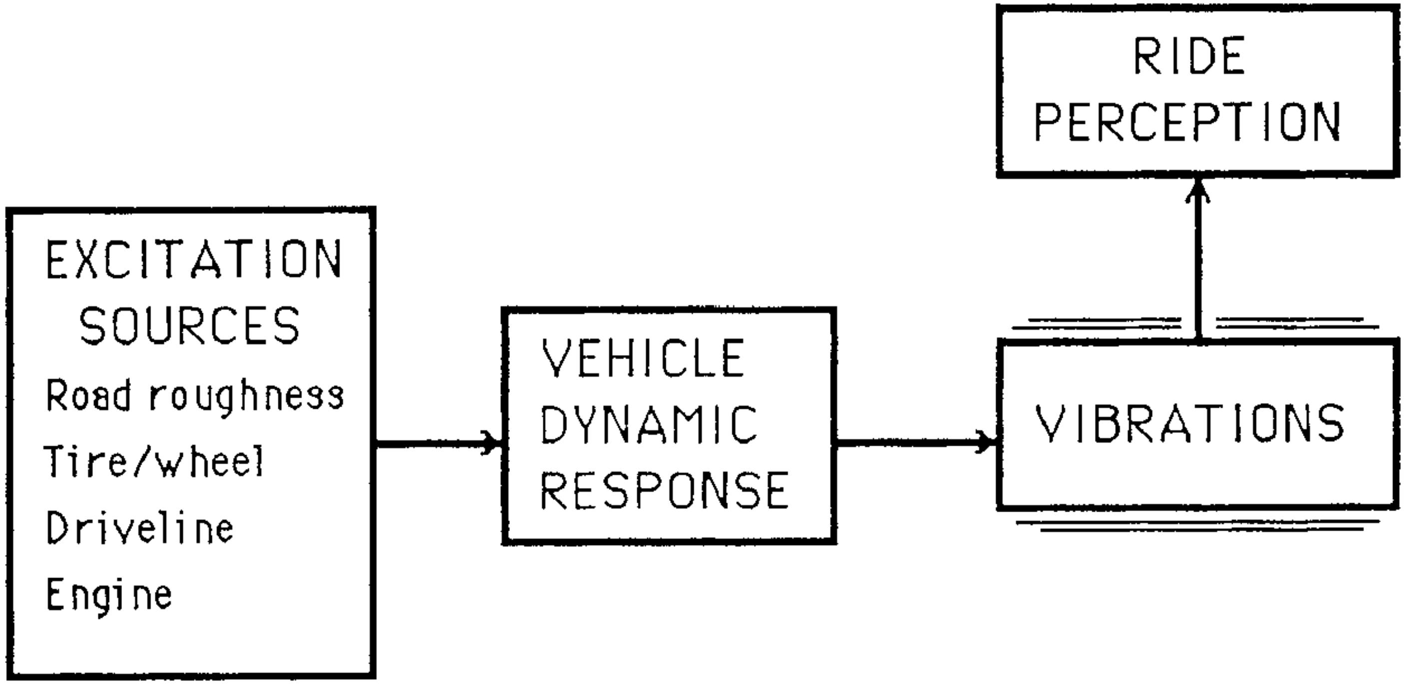
Lecture overview

- Excitation input
- Quarter car model
- Ride response
  - Active suspension
- Human perception

The Ride System

- The Ride System
  - Excitation
  - Response
  - Vibration
  - Perception

- Analyses in time or frequency domains



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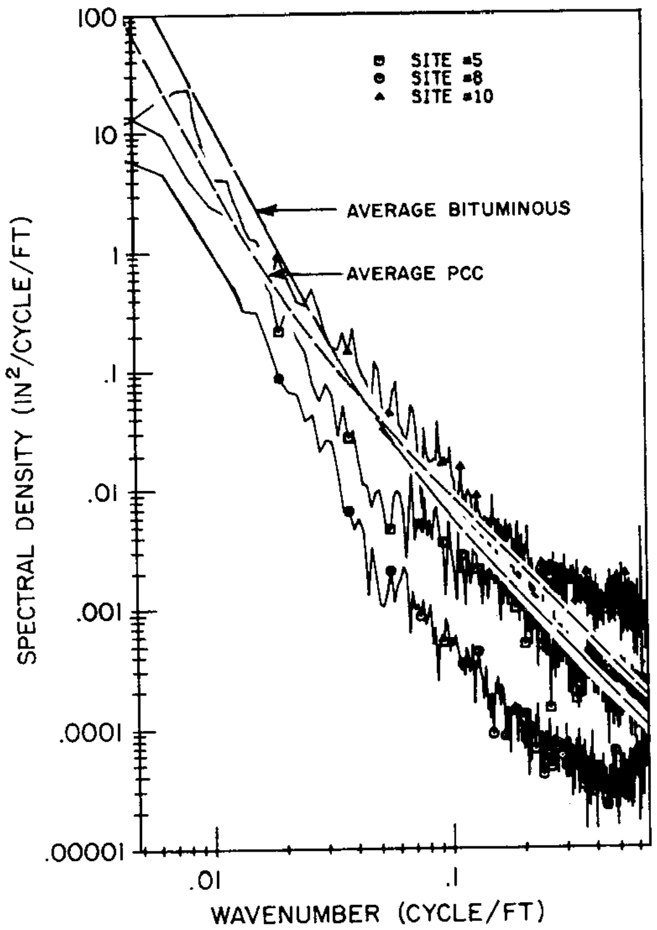
Excitation: Road Roughness

- The road surface is the most significant excitation source.



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Excitation: Road Roughness

- A model for generating excitation input
- Generator source: random sequence
- Described using;

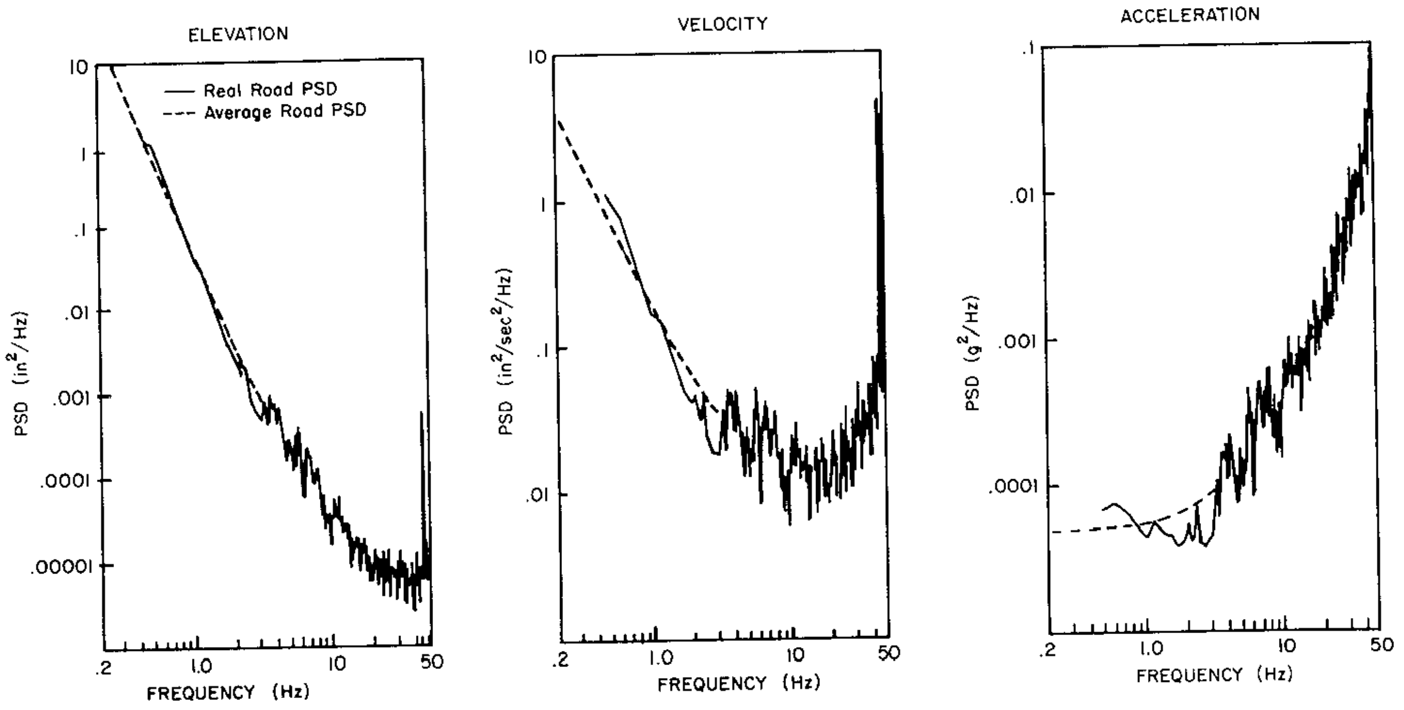
$$G_Z(\upsilon) = G_O\left[1 + (\upsilon_O/\upsilon)^2\right] / (2\pi\upsilon)^2 \qquad [1]$$

where;

$G_Z(\upsilon)$ = PSD amplitude (feet^2/cycle/foot)
υ = Wavenumber (cycles/foot)
G_O = Roughness magnitude parameter (1.25x10^5 for rough roads, 1.25x10^6 for smooth)
υ_O = Cutoff wavenumber (0.02 cycles/foot for rough roads, 0.05 cycles/foot for smooth)

Excitation: Road Roughness

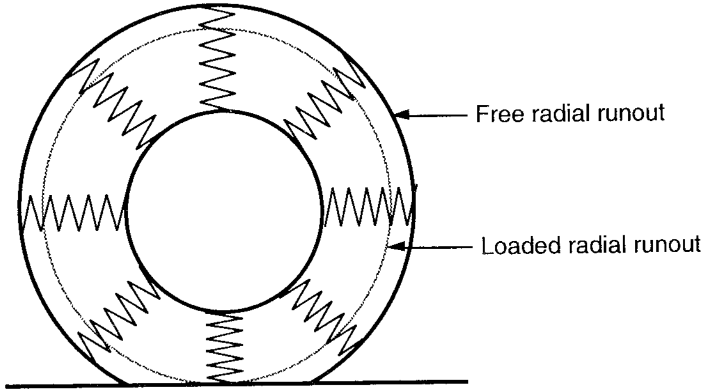
- Simulated roads can be created using [1] or a random number sequence (coloured noise)
- Multiplying cycles/distance (cyc/ft, cyc/m) by vehicle speed gives frequency -> from which PSD can be plotted.



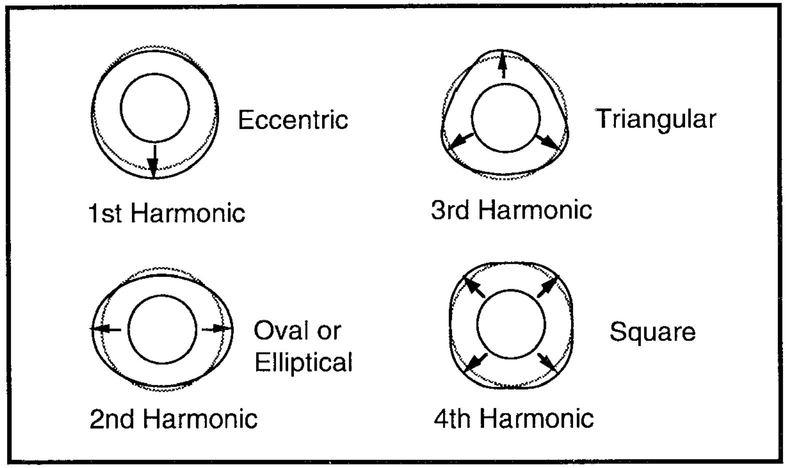
Frequency [cyc/s] = wave number [cyc/m] x speed [m/s]

Excitation: Secondary Effects

- Secondary effects include vibration
  - Driveline
  - Engine
  - Wheel/tyre
- Typically, at higher frequency than primary excitation sources
- Runout occurs due to deformation of the tyre. Imperfections result in different harmonics i.e., mode shapes



'Runout' due to tyre deformation



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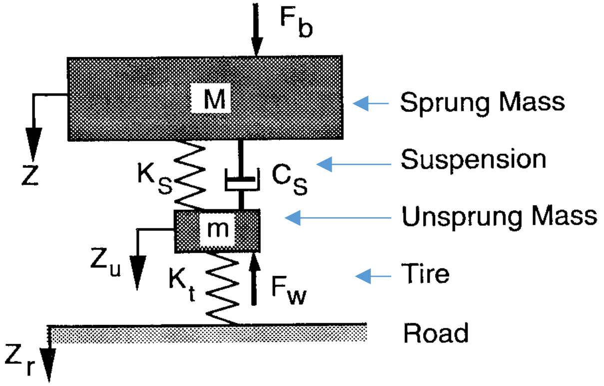
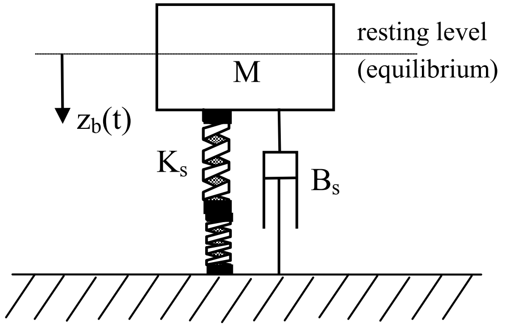
The Quarter Car Model

- The simplest 'useful' representation of vertical ride dynamics

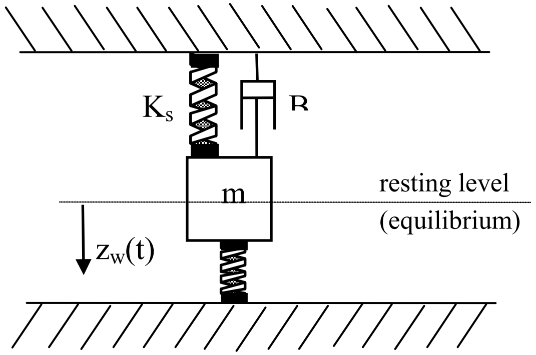


$M = 300$kg
$m = 30$kg
$K_s = 20000$ N/m
$K_t = 160000$ N/m
$C_s = 1500$ Ns/m (also written as B_s below)

- More simple representations (for quick calcs) is possible considering different modes in isolation.



Body bounce



Wheel hop

The Quarter Car Model: Body bounce

- Considering body bounce (springs acting in series);

$$K_{bb} = \frac{K_s K_t}{K_s + K_t}$$

- The natural frequency, ω_n;

$$\omega_n = \sqrt{\frac{K_{bb}}{M}}$$

- The actual response is damped by the damping ratio, ζ (typically 0.2 – 0.4)

$$\omega_d = \omega_n \sqrt{1 - \zeta} \quad \text{with} \quad \zeta = \frac{B_s}{\sqrt{4K_{bb}M}}$$

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The Quarter Car Model: Wheel hop

- For wheel hop;

$$K_{wh} = K_s + K_t$$

- So that the natural frequency, ω_n

$$\omega_n = \sqrt{\frac{K_{wh}}{m}}$$

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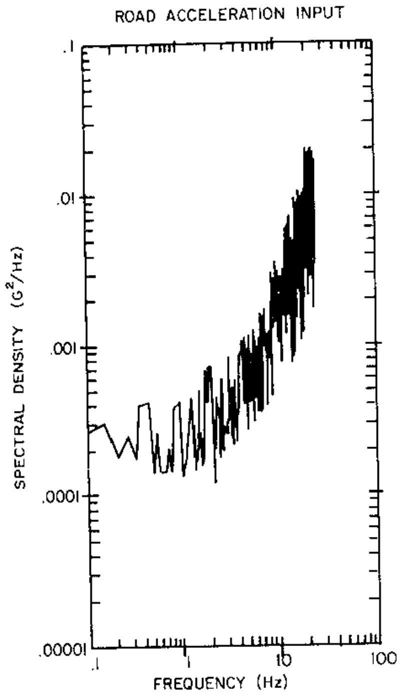
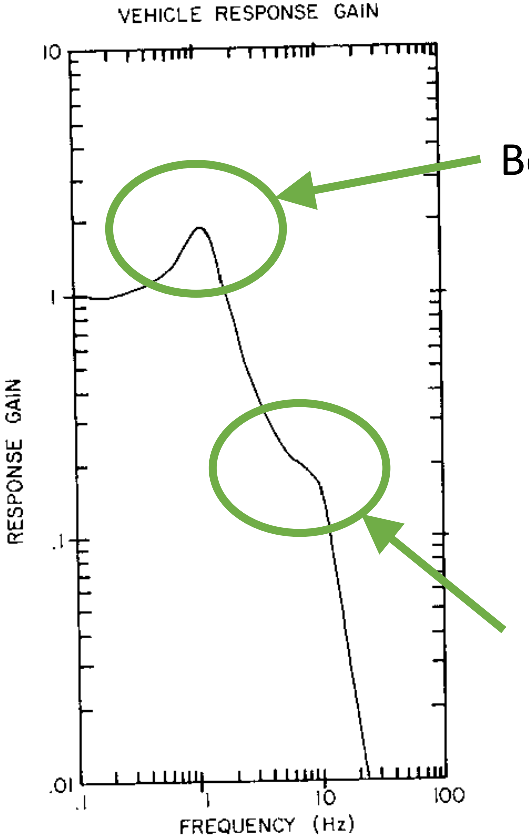
Ride Response

Input: from road



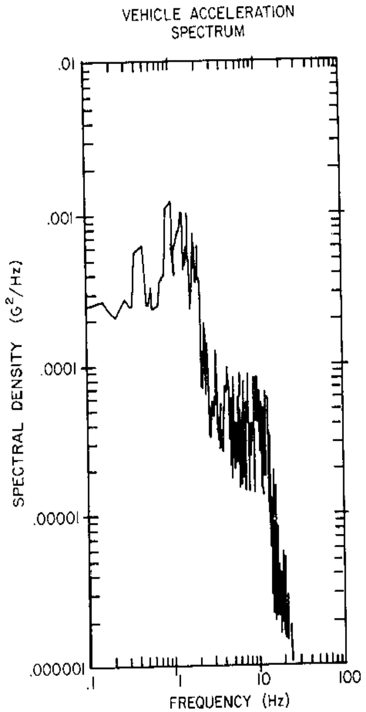
Modelled system



Body bounce

Wheel hop

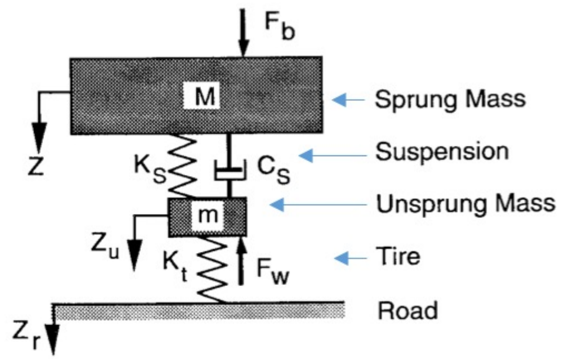
Output: suspension response

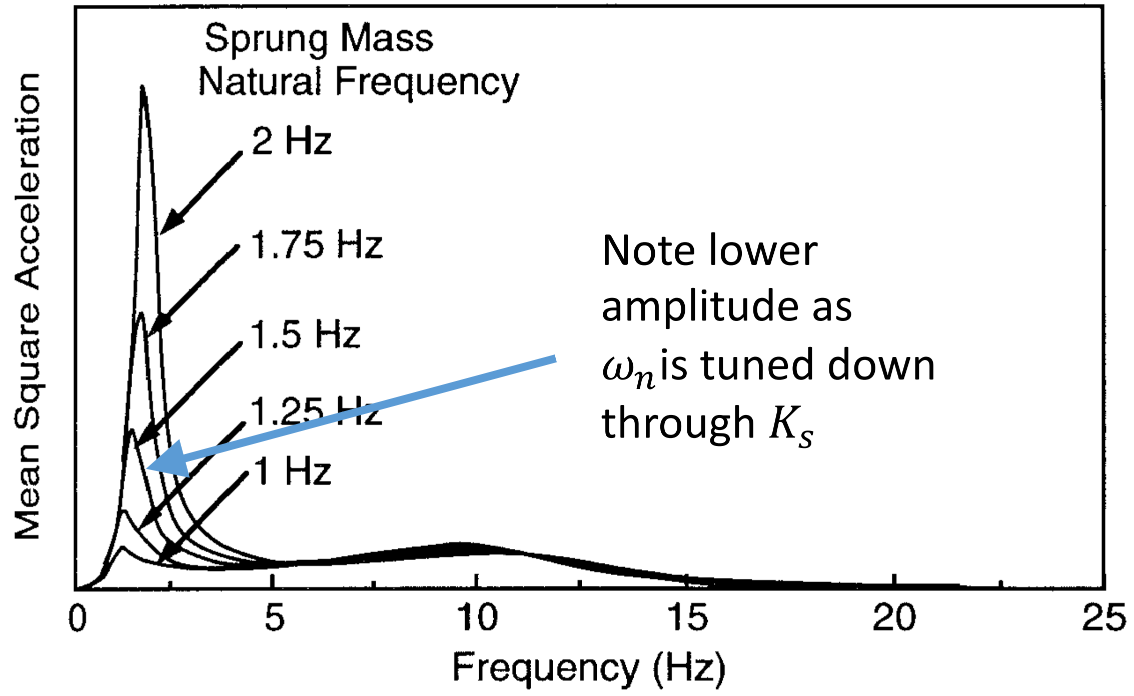


High frequency attenuation

Ride Response

- ω_n of the sprung mass can be changed by changing stiffness, K_{bb}.
- K_s and K_t act in series. K_t is significantly stiffer and therefore the response is dominated by K_s.
- Limited by;
  - Suspension travel
  - Handling performance
  - Nausea

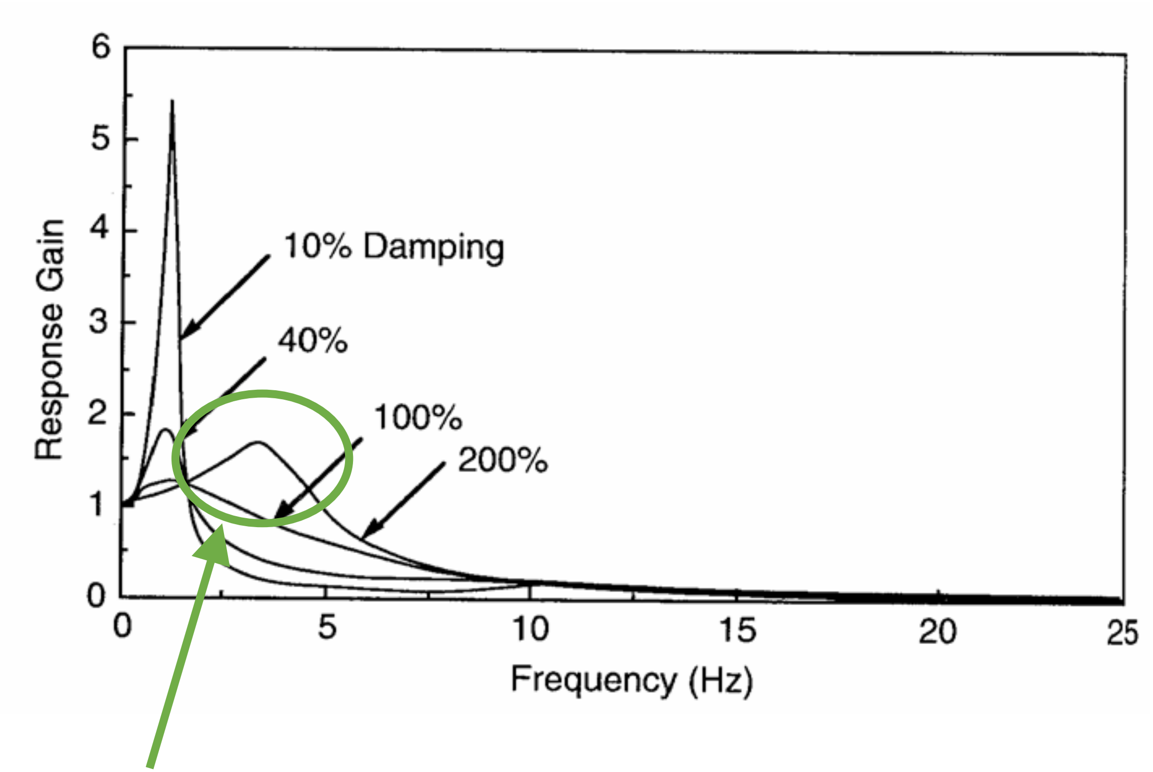




Changes to K_s to change ω_n of the sprung mass.

Ride Response

- By changing damping also, the peak body response can be reduced.
- There are other consequences though for the higher frequencies whose transmission to the body becomes greater.



Effectively ‘tied’ together body and wheel.

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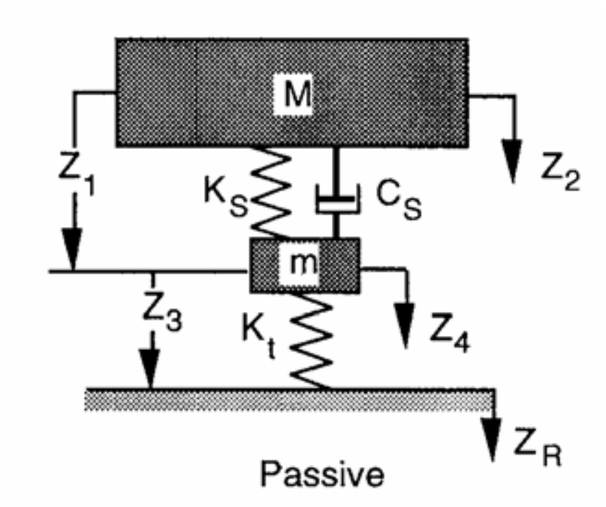
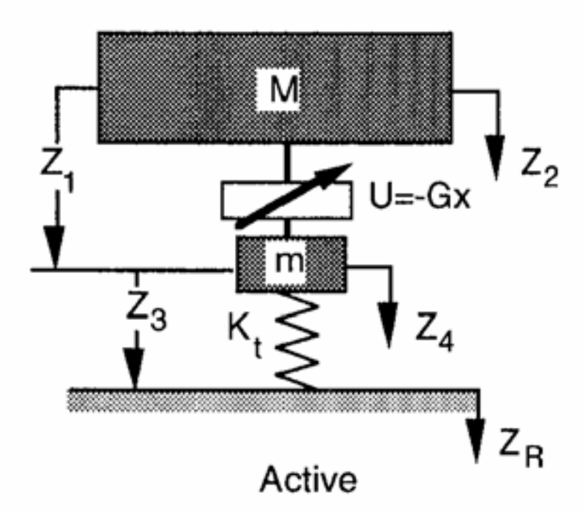
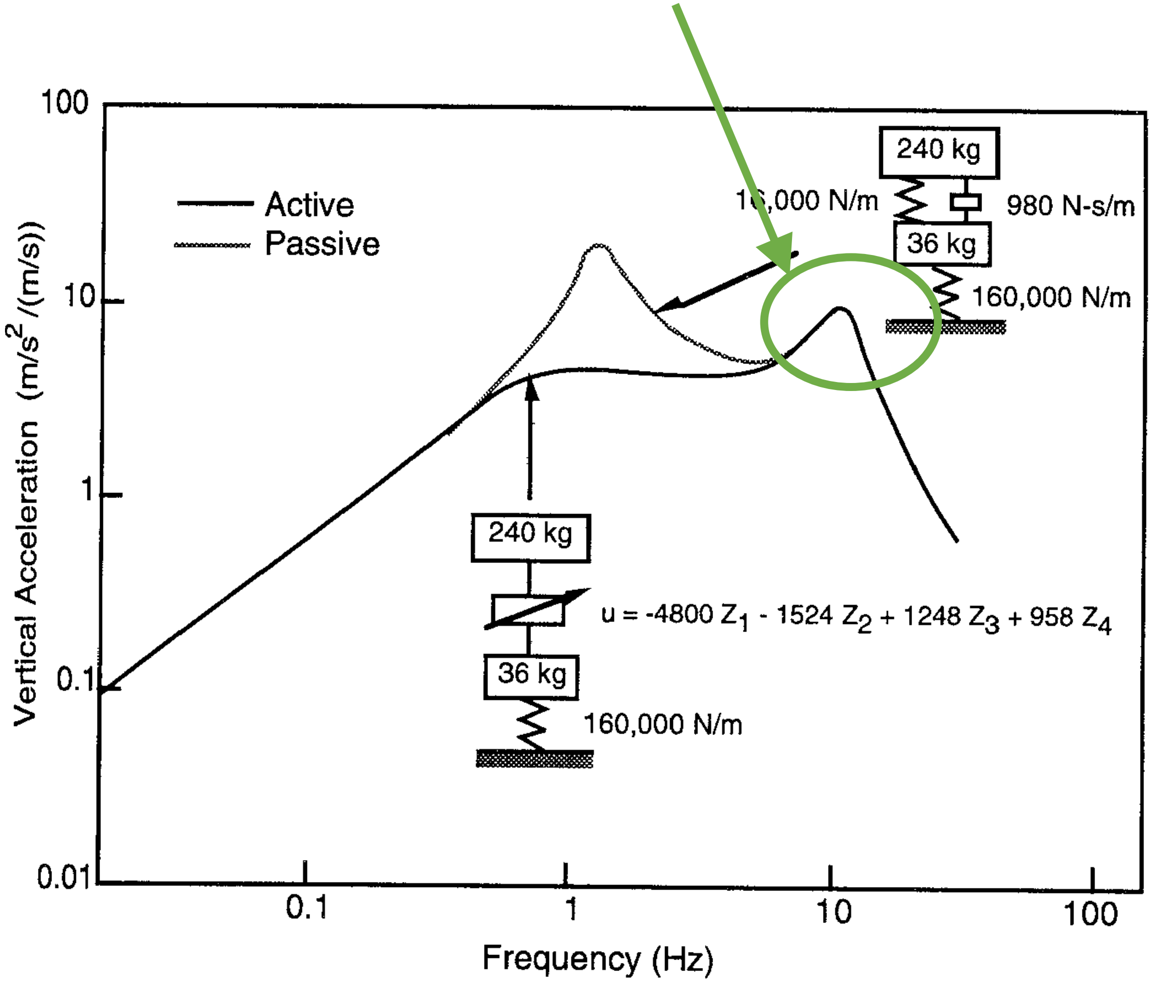
Active Suspension



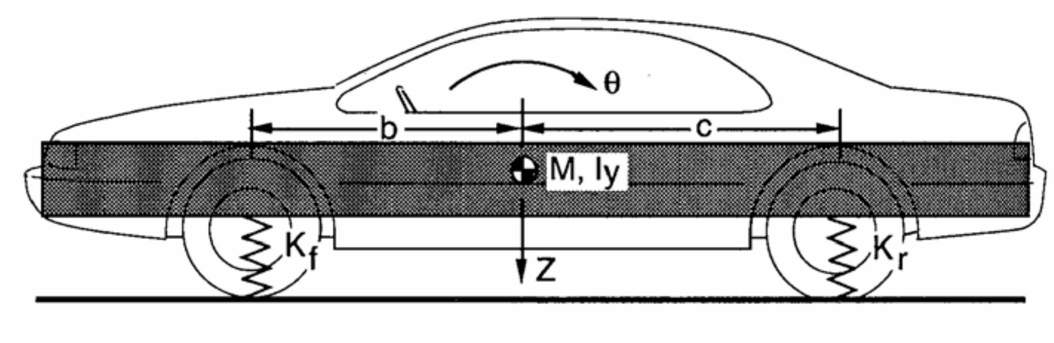


Less easy to manage wheel hop



Bounce and Pitch

- Quarter car model – good for body bounce analysis
- Half car model required for pitch and bounce analysis
- What you feel depends on where you are (centre vs one end or the other)
- Principle problem with pitch is the fore-aft motion it causes – nausea!



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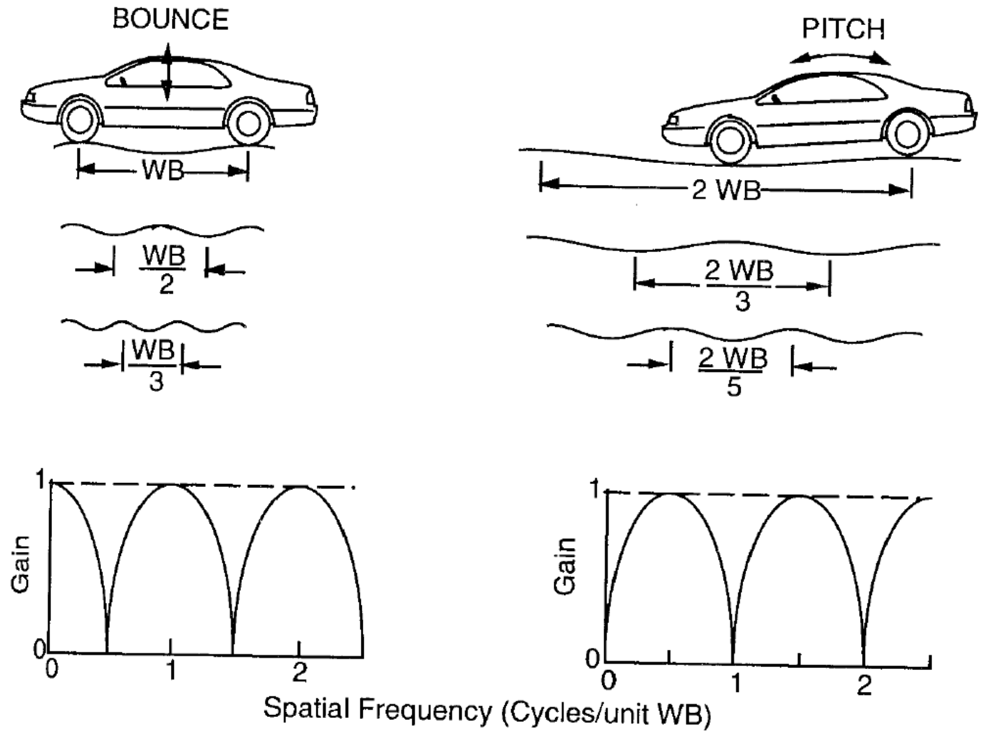
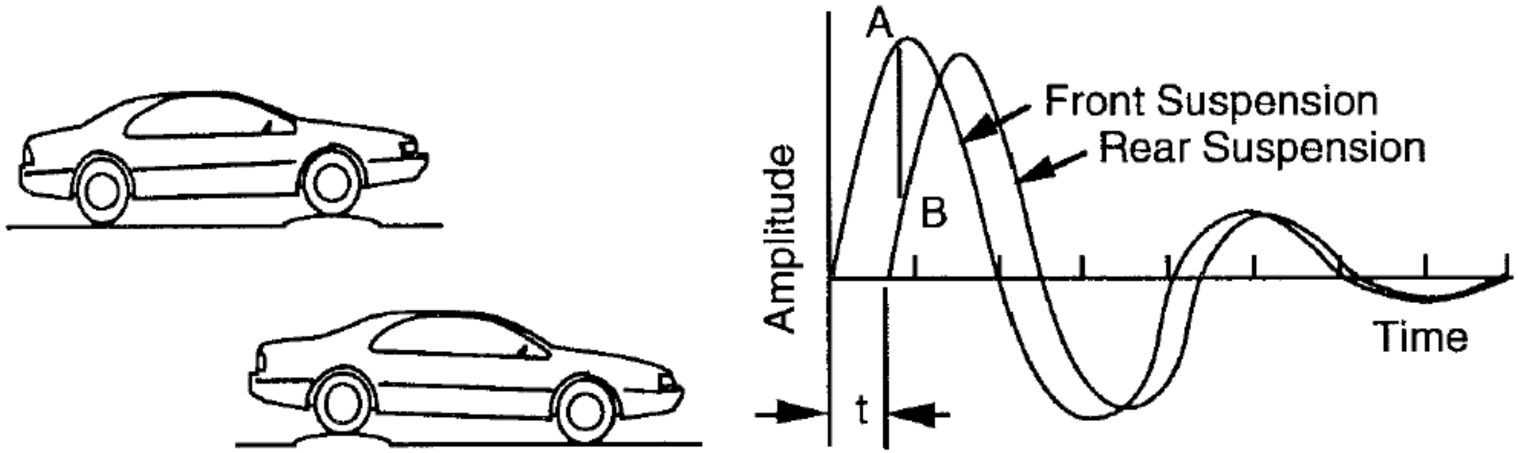
Bounce and Pitch: Wheelbase Filtering

- Spacing of the front and rear suspensions can couple with road 'wavelength'.
- Very few roads are sinusoidal!



Bounce and Pitch: Ride Rates

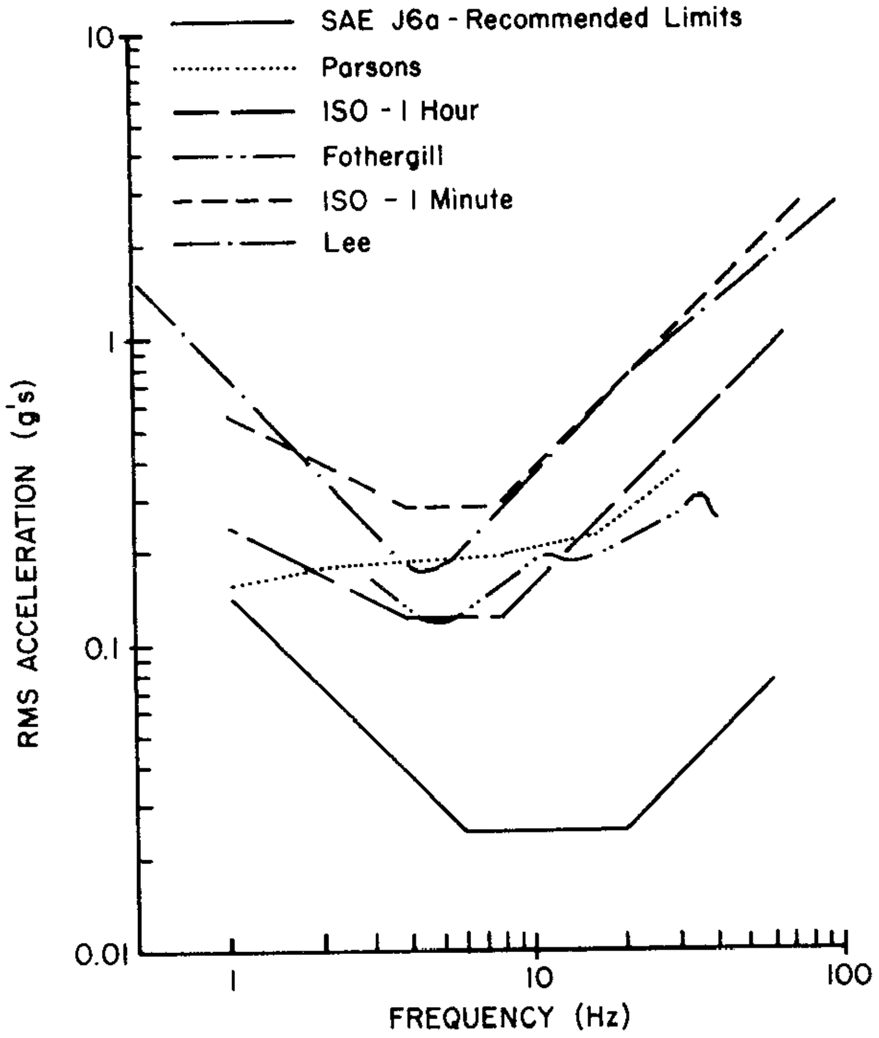


- By making front ride rate lower it is possible to reduce the discomfort of pitching.
- As you hit a bump this induces pitch but resolves to bounce as the rear end 'catches up' with the front.

Human Perception

- We are interested in human perception
- Much like the vehicle the human body responds to different ’excitation’ frequencies in different ways.

Ride discomfort (lines of equal tolerance) - vertical



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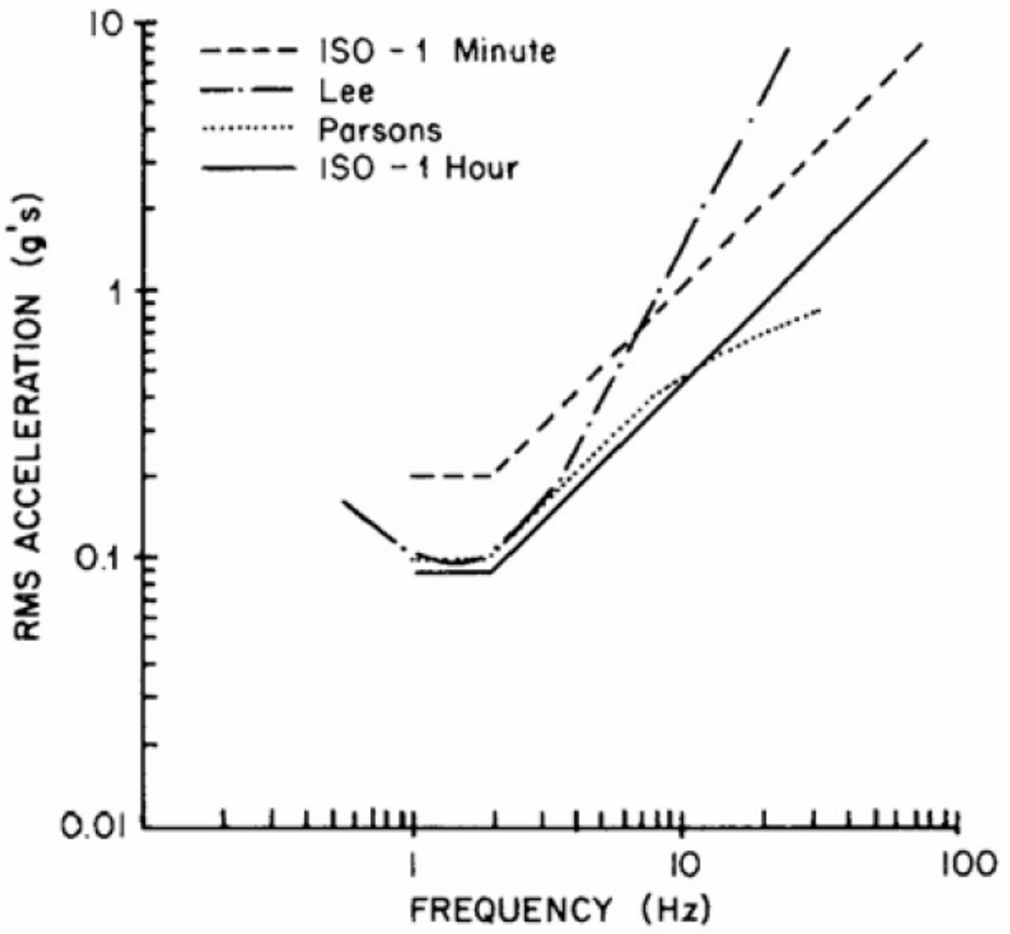
Human Perception

- Fore-aft vibration lines of 'equal comfort'
- Fore-aft tolerance no the same as vertical tolerance.

Ride discomfort (lines of equal tolerance) – fore-aft



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Conclusions

- Excitation input
- Quarter car model
- Ride response
  - Active suspension
- Human perception

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