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OF TECHNOLOGY

Virtual prototyping for green road design

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Sustainable Transportation



SAFE
(Handling, comfort)

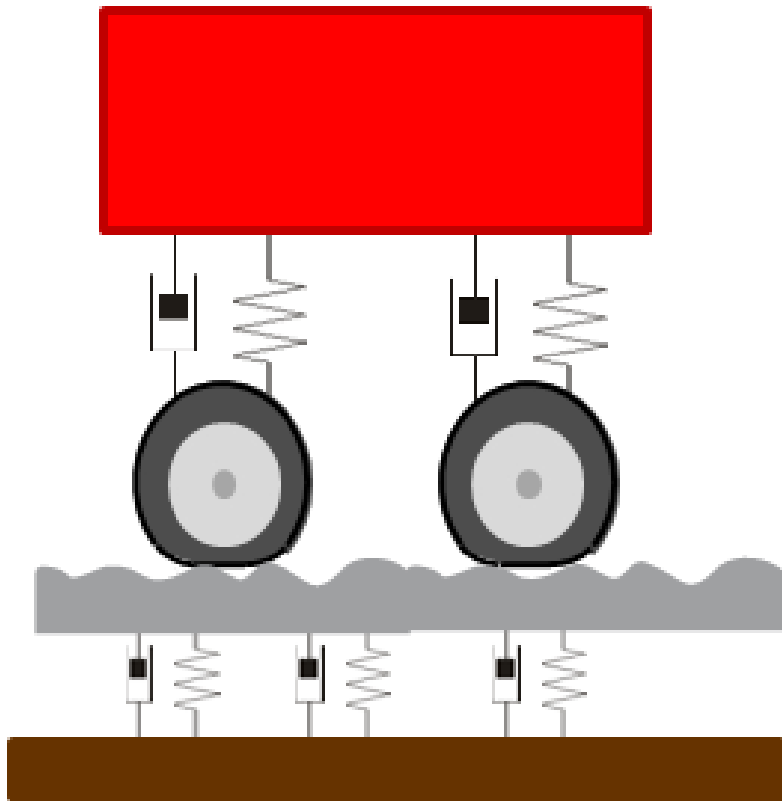
CLEAN
(Rolling resistance,
tire wear and road wear)

SILENT
(Interior and
exterior noise)

Long term goal

Virtual prototyping for **green** vehicle&road **design**

KEY: Understanding tyre/road contact!



- **Vehicle properties:**
 - Energy losses in suspension
 - Load and speed
- **Tyre properties:**
 - Material properties
 - Tyre structure
- **Road properties:**
 - Texture
 - Material properties

Today

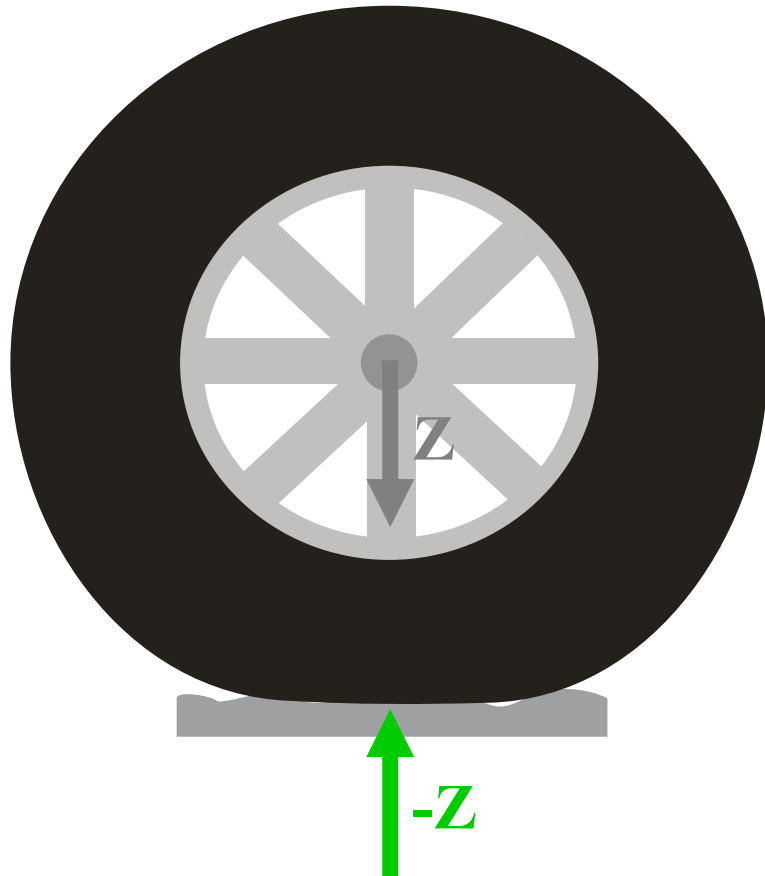
- What's rolling resistance?
 - Tyre influence
 - Vehicle influence
 - Road influence
-

Rolling resistance & Environment

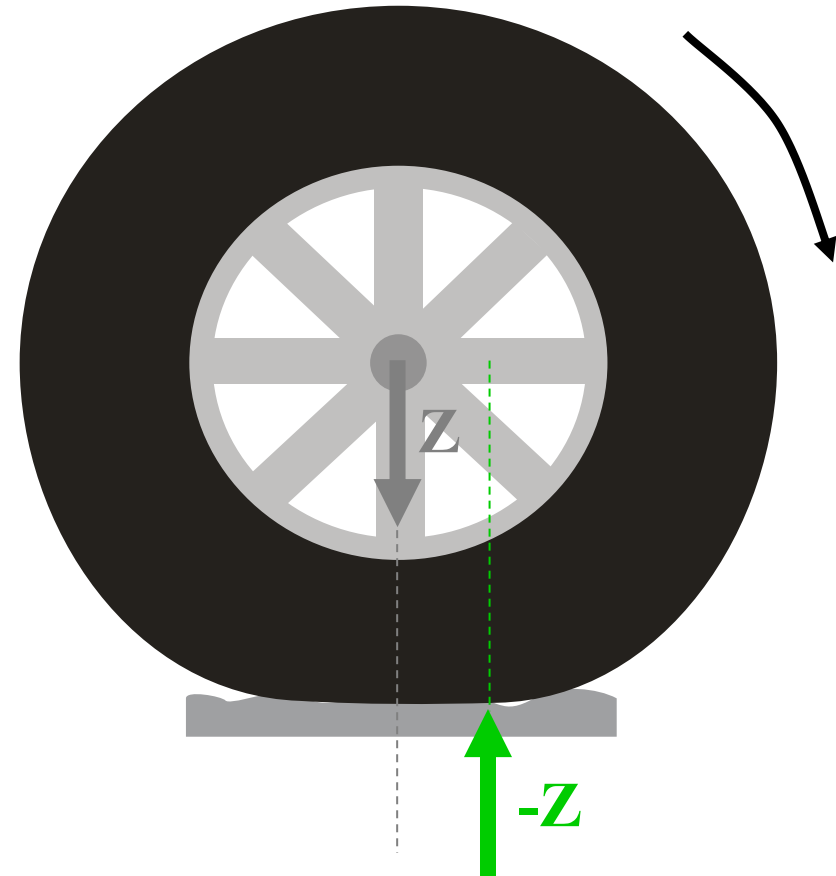
- Energy losses imply increased fuel consumption
 - 10% less rolling resistance means:
 - Cars: 0.5 to 1.5 % less fuel consumption
 - Trucks: 1.5 to 3 % less fuel consumption
 - Less fuel consumption → reduction CO2 emissions
-

What is rolling resistance?

STANDING STILL

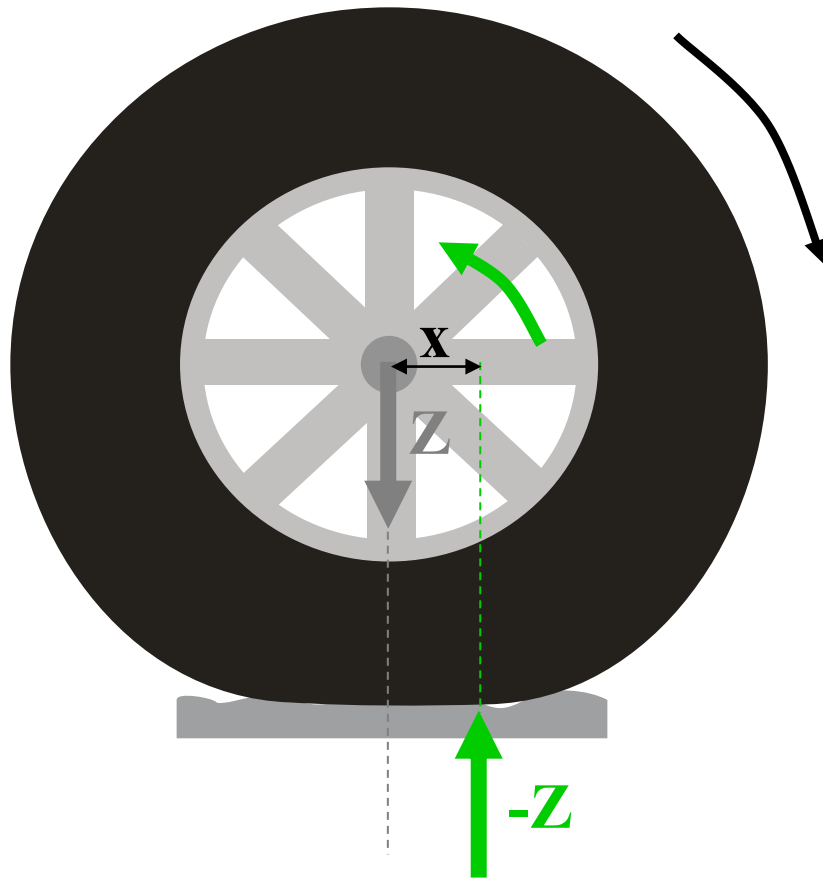


ROLLING

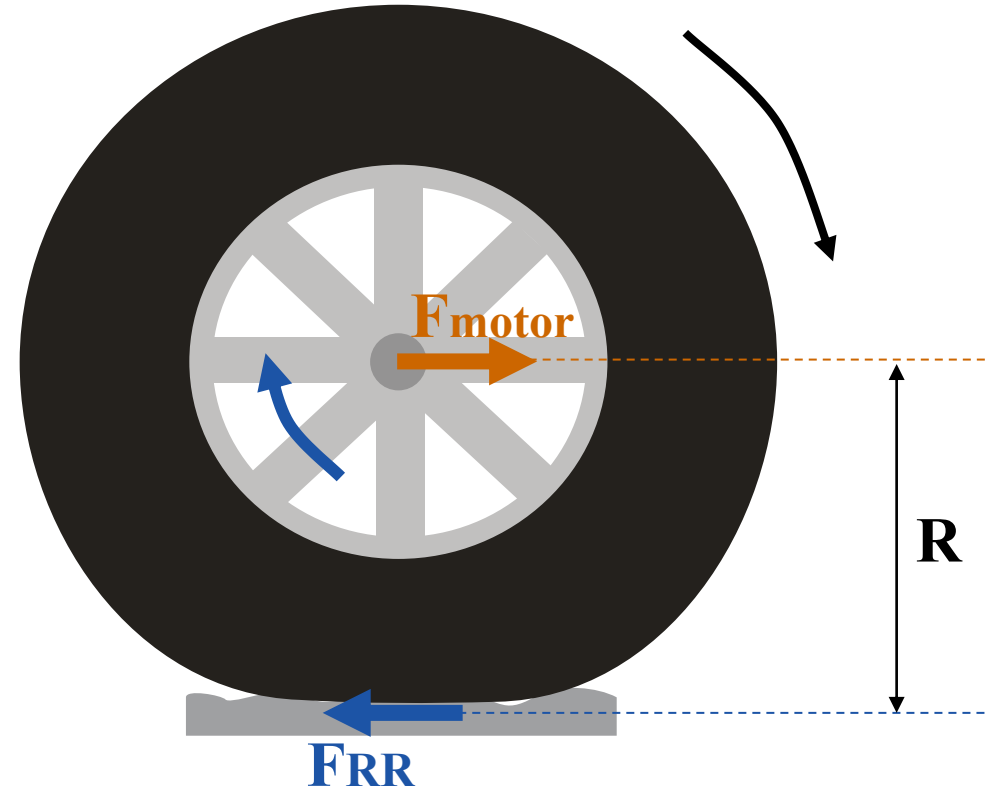


What is rolling resistance?

TORQUE



COMPENSATING TORQUE



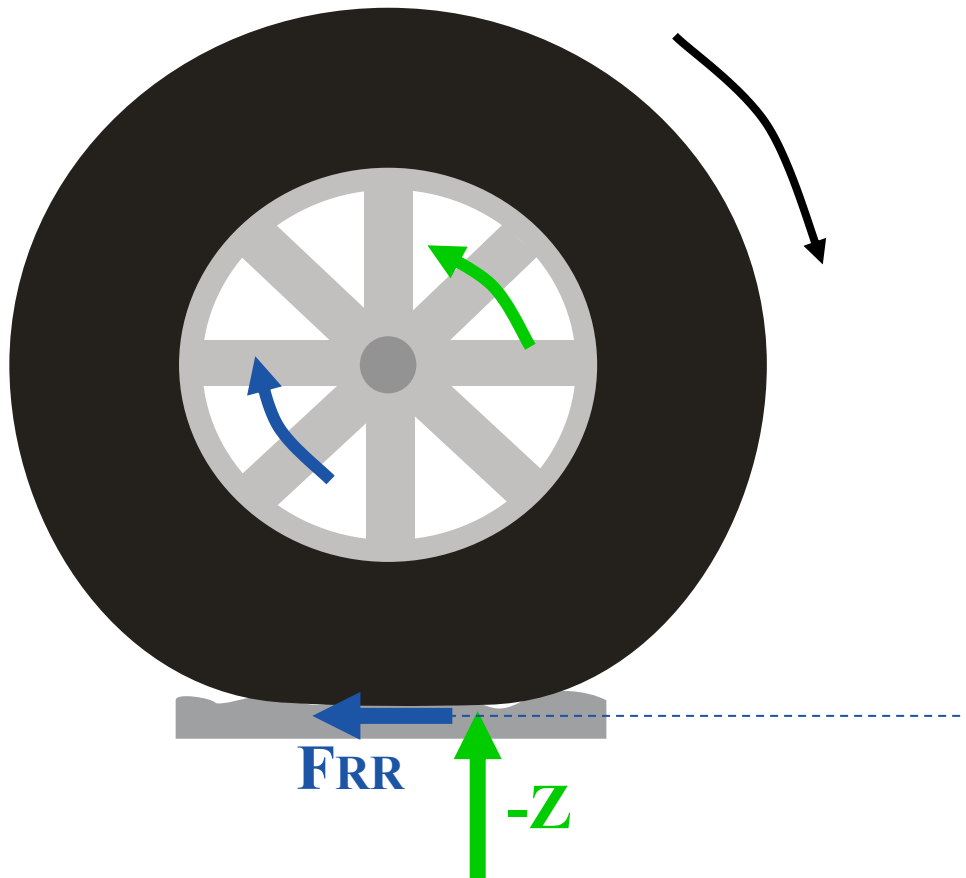
What is rolling resistance?

- Rolling resistance coefficient

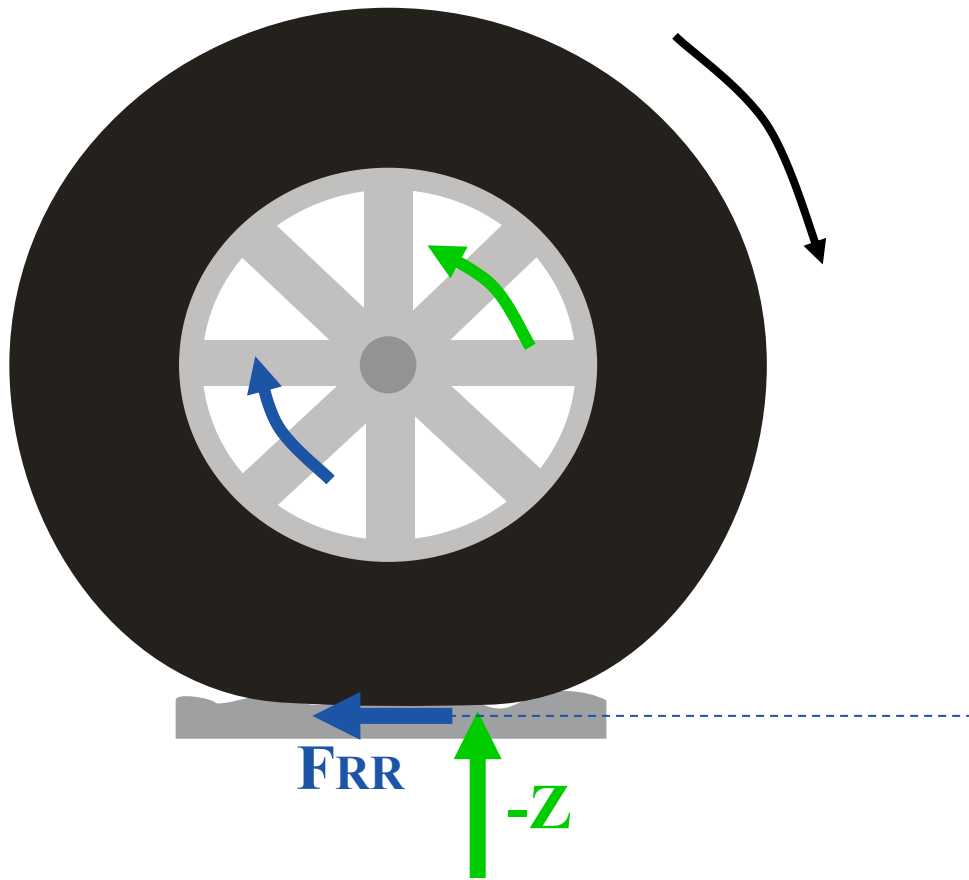
$$C_{RR} = \frac{F_{RR}}{Z}$$

- Car tyres 0.8 - 1.2%
- Truck tyres 0.4 - 1%

- Cause: Energy losses mainly due to cyclic deformation of tyre cross-section (90%)



Solution?



- Responsible: Viscoelastic properties of rubber.
- Solution: make purely elastic rubber?



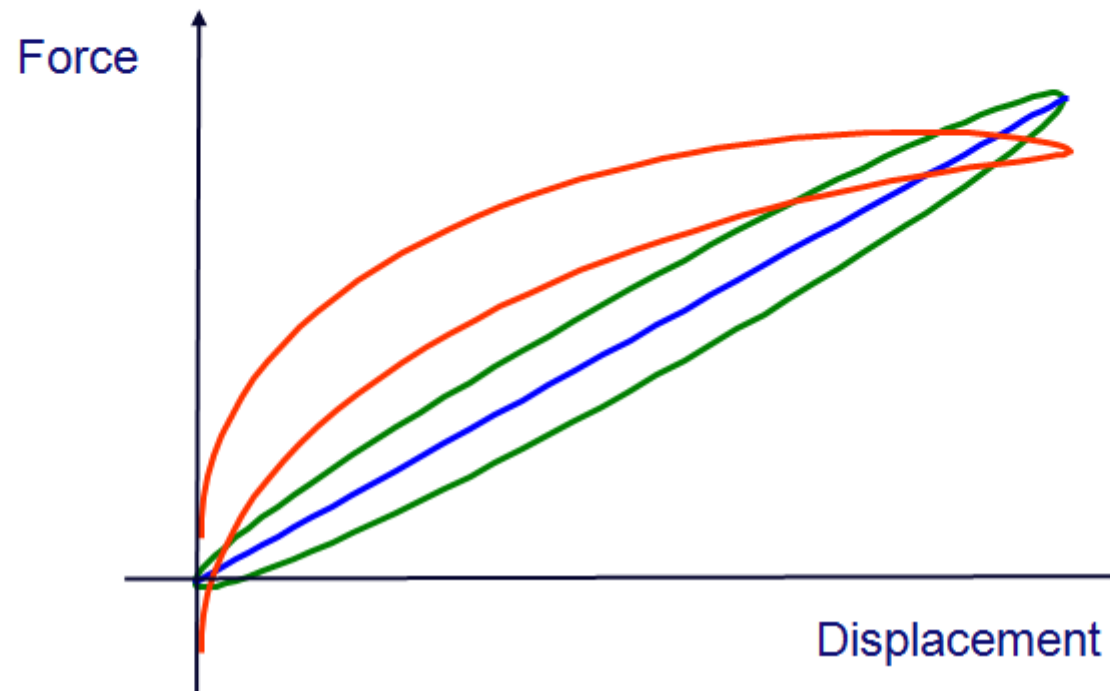
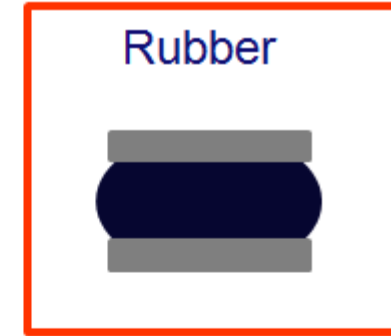
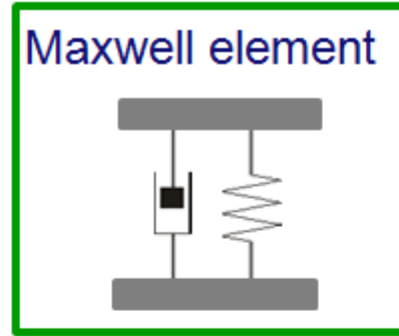
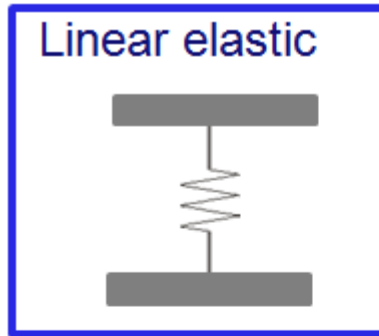
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No rolling resistance....

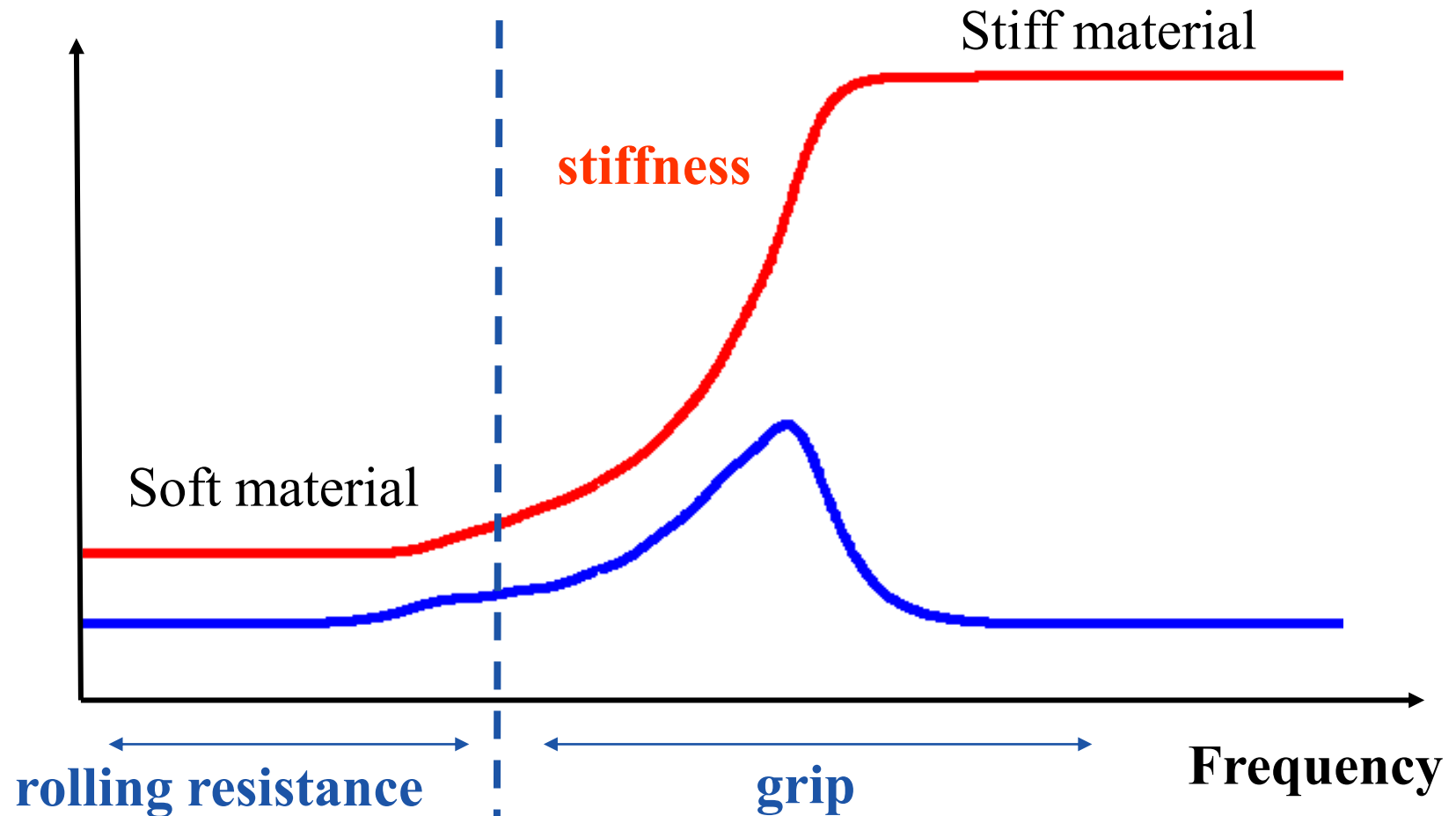
NO GRIP!



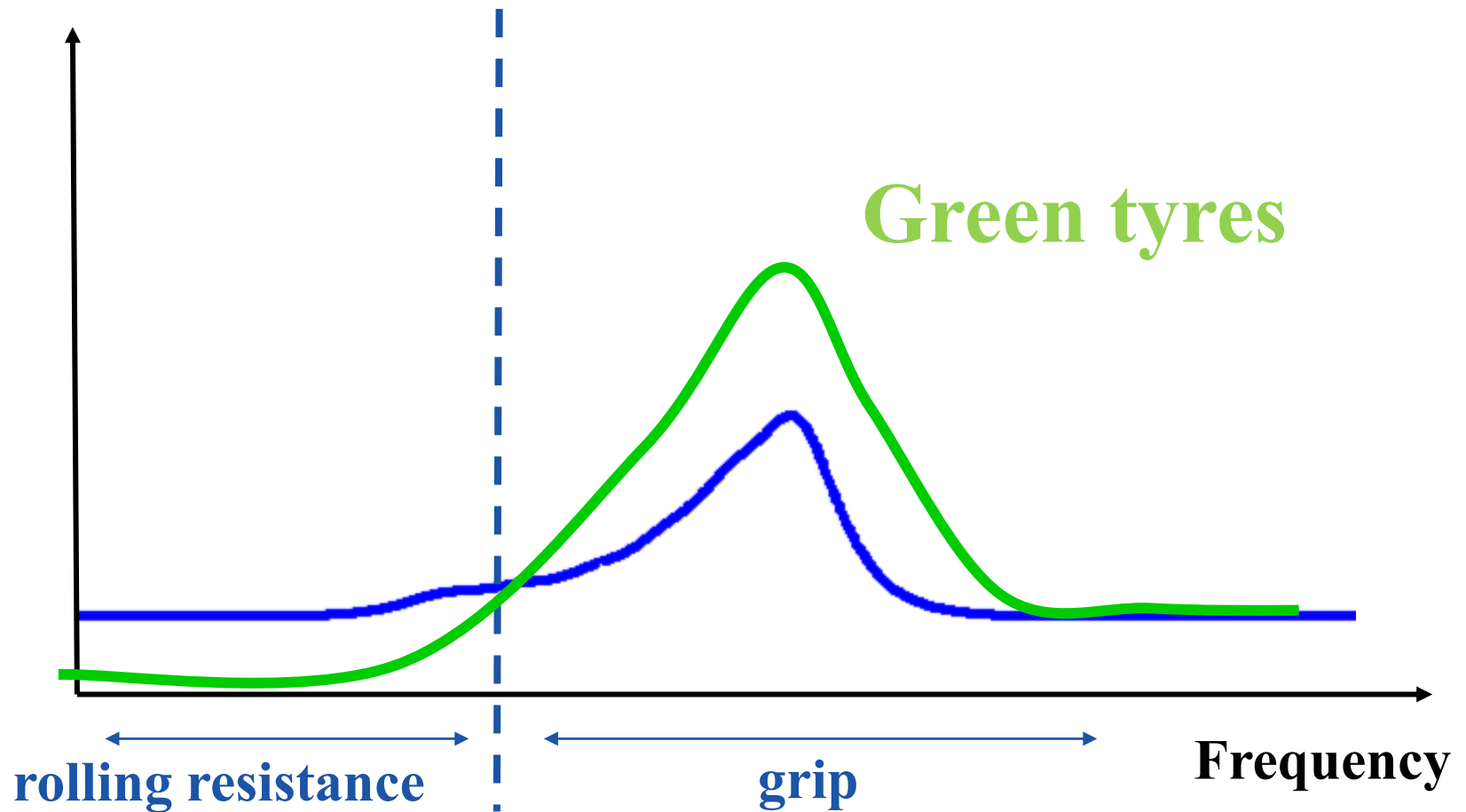
Elastic versus viscoelastic behavior



Rubber properties



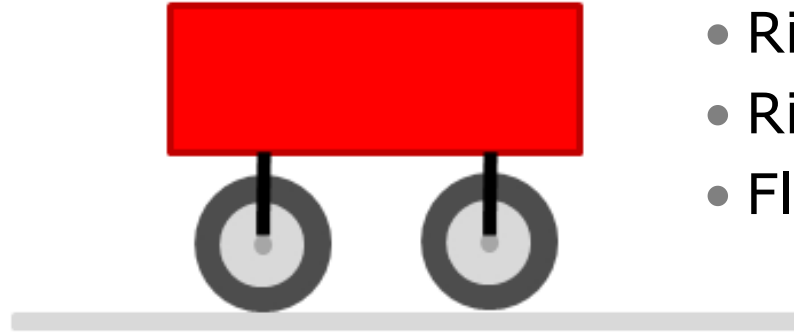
Rubber properties



Rolling resistance & Tyre properties

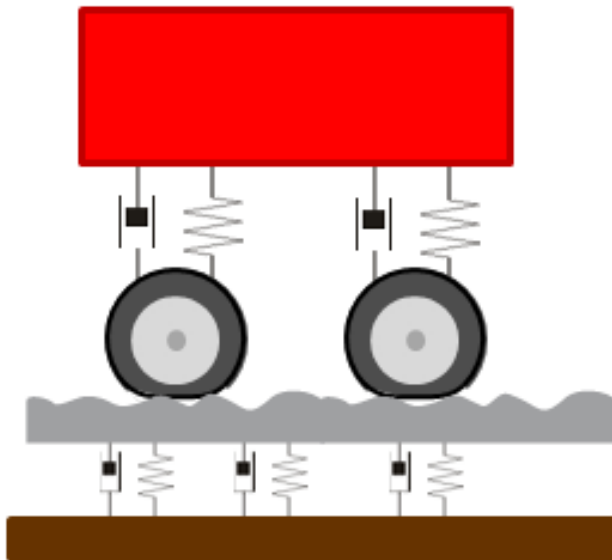
- Rolling resistance very sensitive to changes in tyre properties due to ...
 - Temperature changes: summer, winter
 - Time: new/worn tyres, aging of rubber
 - Tyre size: passenger car/ truck
 - Tyre contribution to rolling resistance depends also on...
 - Road properties: texture, flexibility, damage ...
 - Vehicle properties: speed, load,
-

Vehicle load



Constant load requires:

- Rigid tyre
- Rigid suspension
- Flat and rigid road

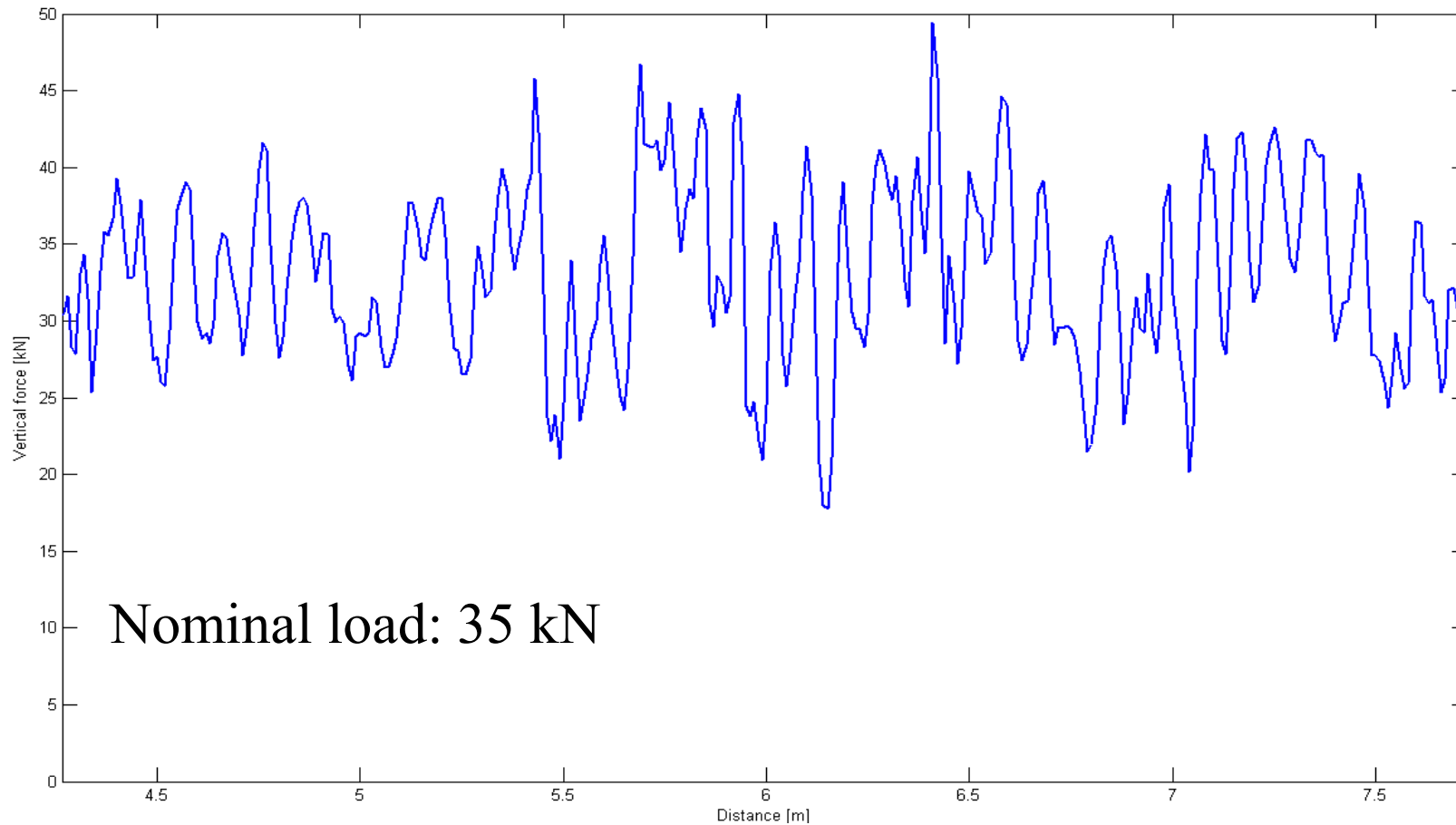


Reality:

- Flexible tyre
- Flexible suspension
- Rough road
- Flexible road?

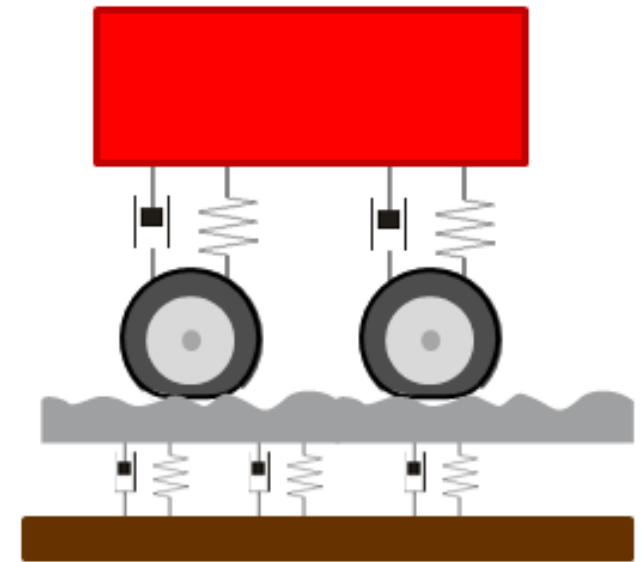
Dynamic load due to vehicle/road interaction

50% load variations for a height variation of 0.01 m

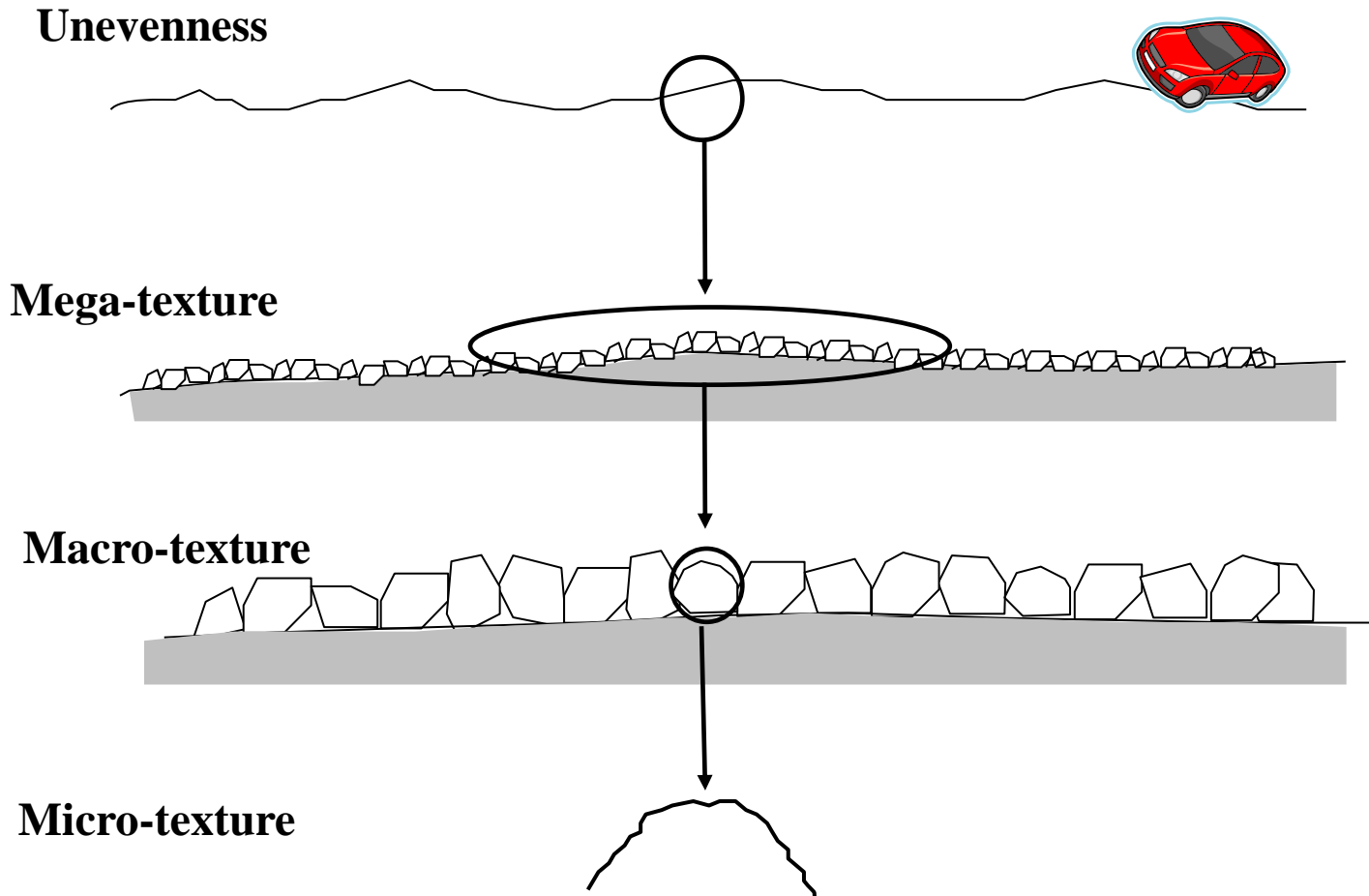


Influence dynamic load on rolling resistance

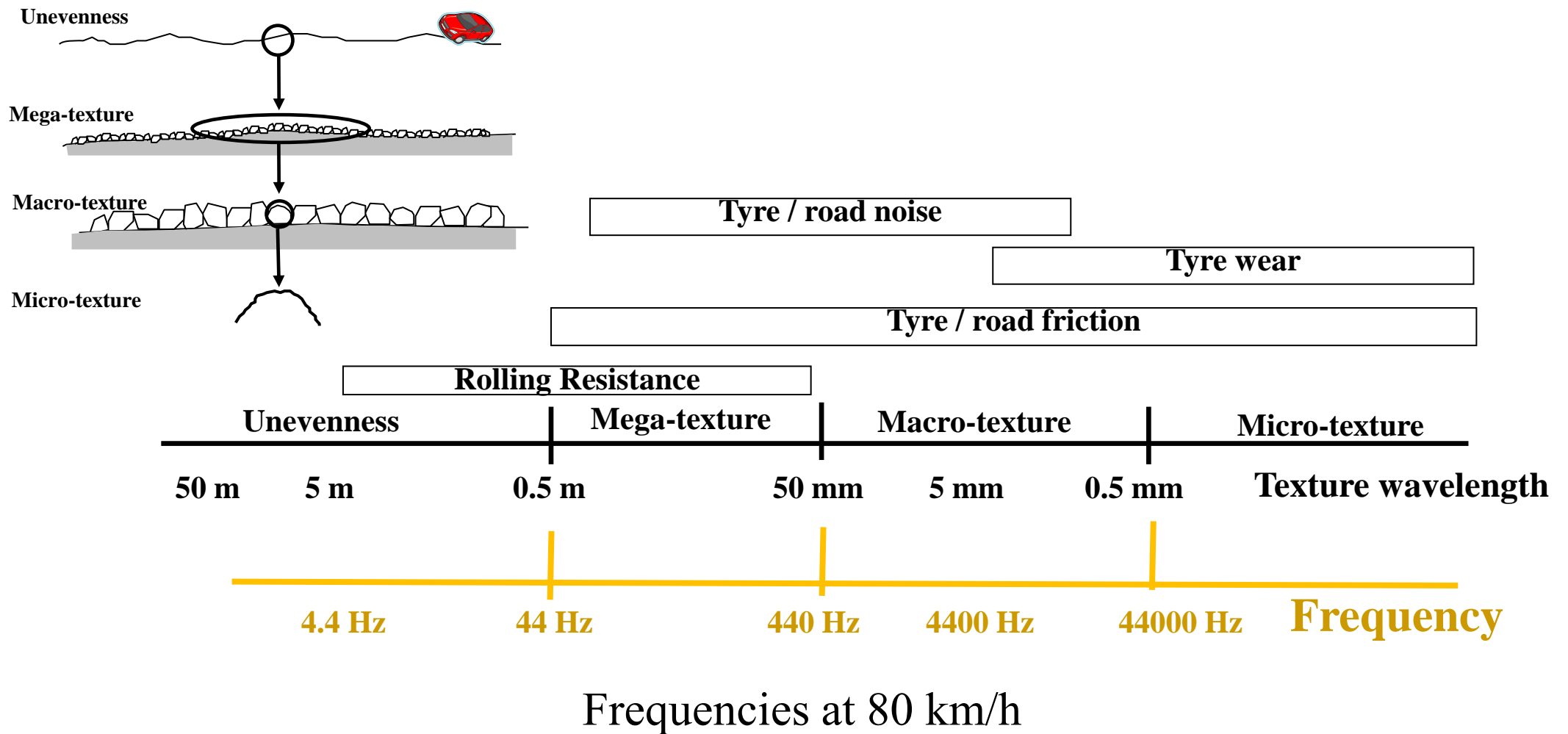
- 50% variation of the dynamic load leads to a variation of approximately 40% of the rolling resistance force.
- Interaction with the road unevenness (wavelengths $> 0.5\text{m}$) leads to:
 - Additional losses in the tyre.
 - Losses in the vehicle suspension.
 - Losses in the road (rubberized surfaces).
 - Road wear



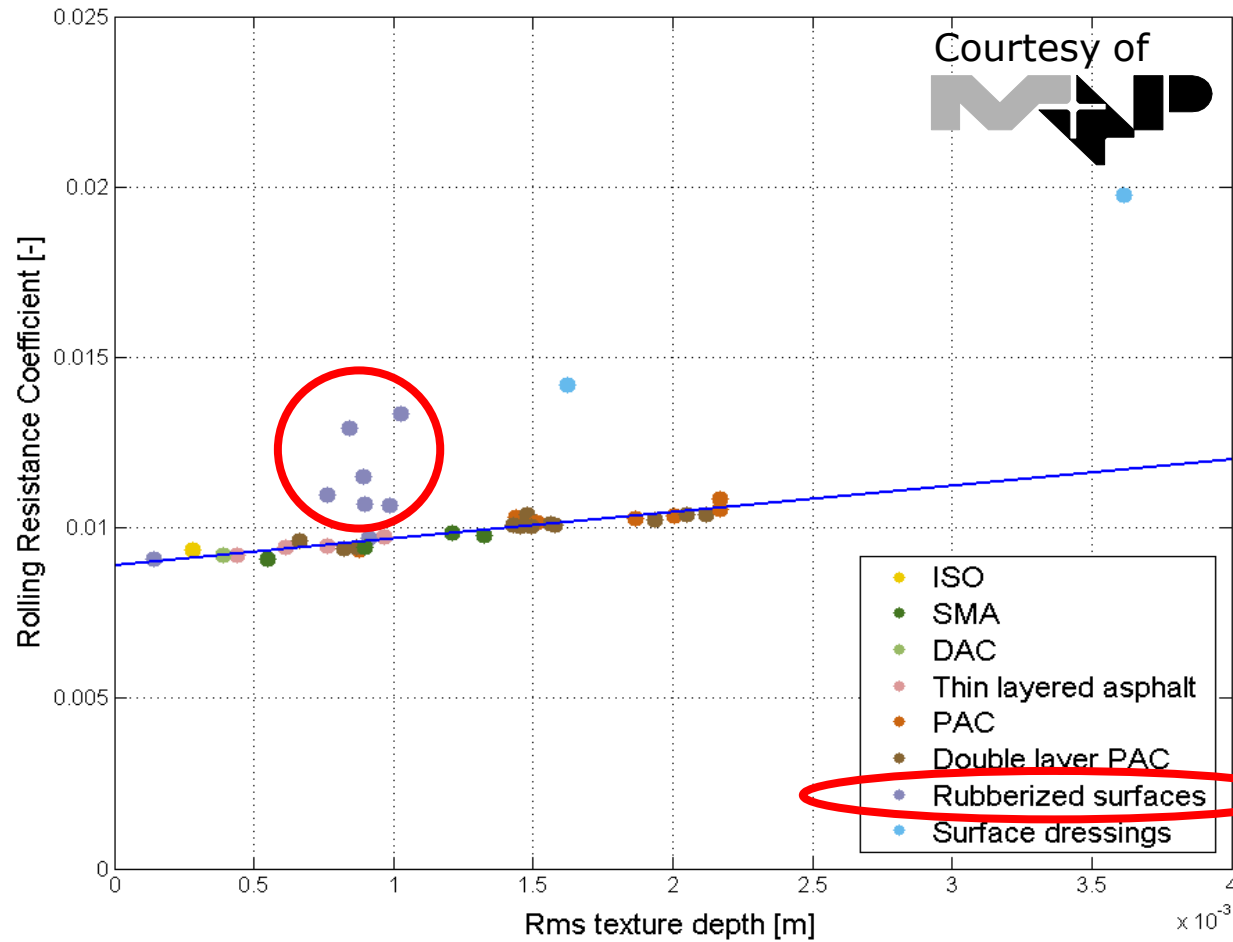
Road texture



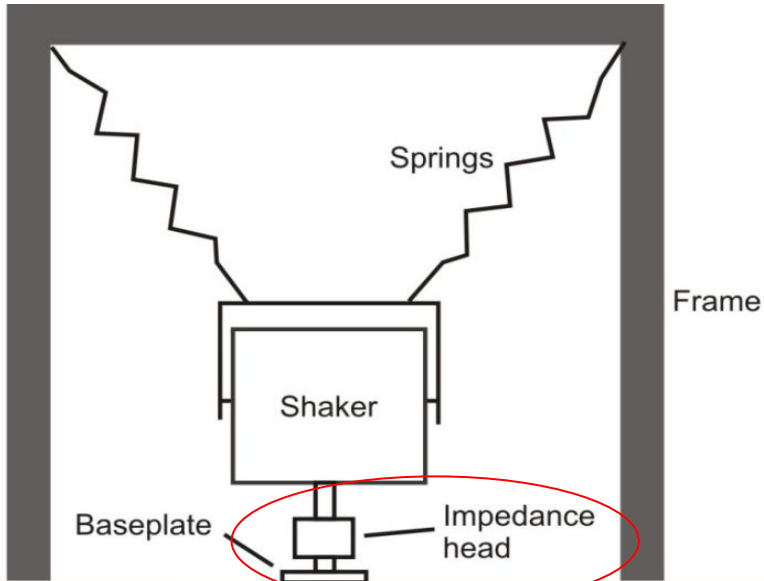
Rolling resistance & Road texture



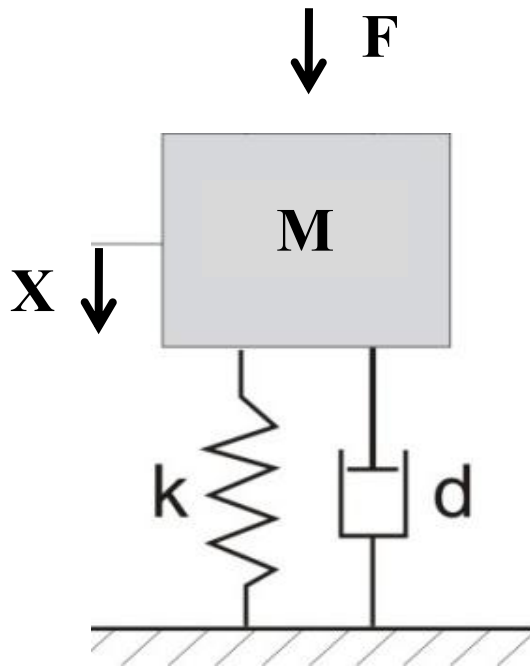
Rolling resistance vs. road texture depth



Road impedance



Road impedance



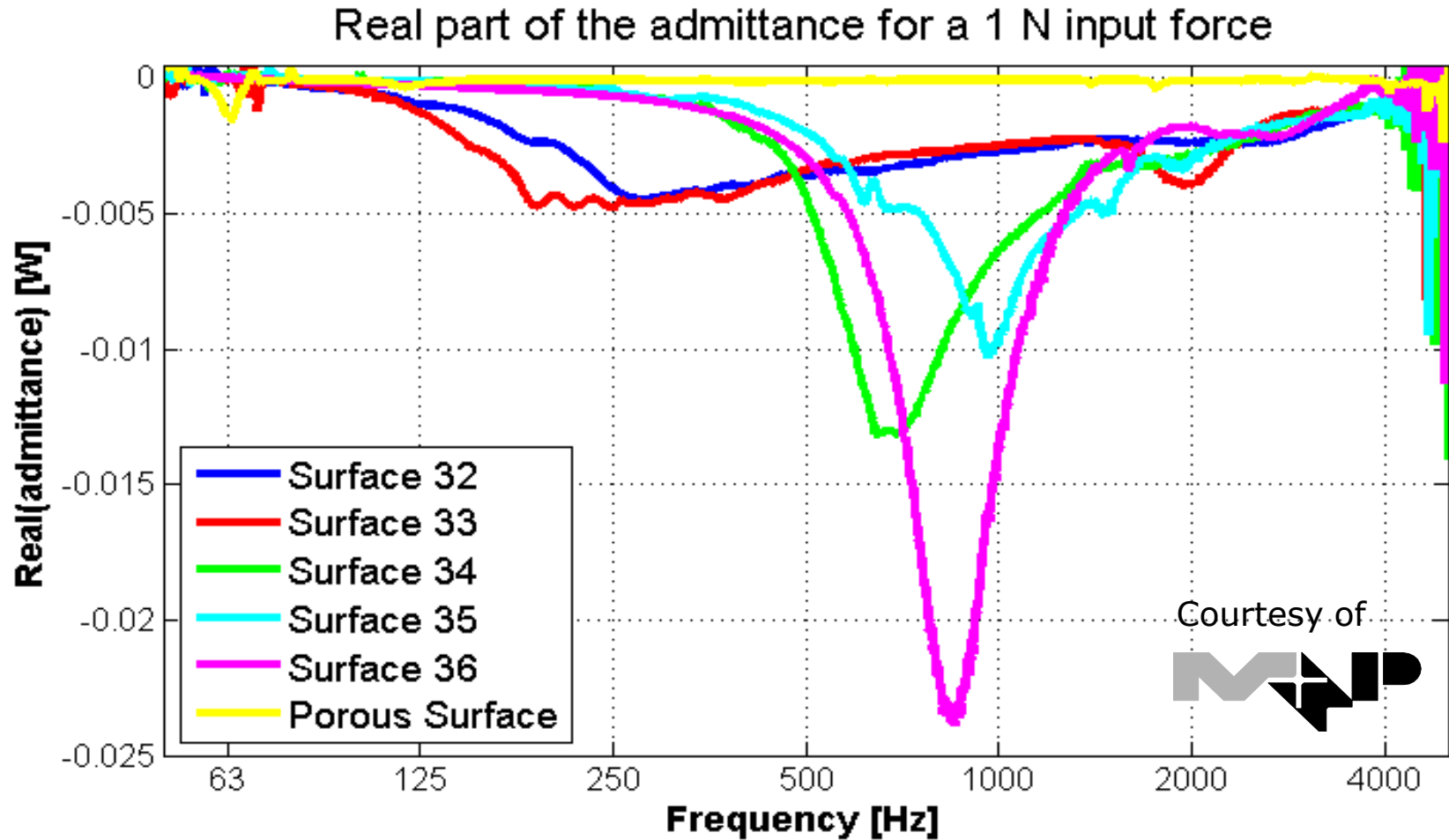
Impedance: $Z = \frac{F}{X}$

Admittance: $A = \frac{X}{F}$

Energy dissipation

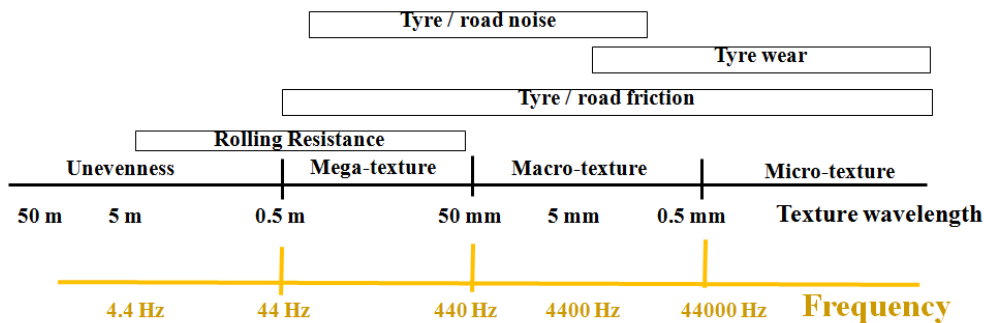
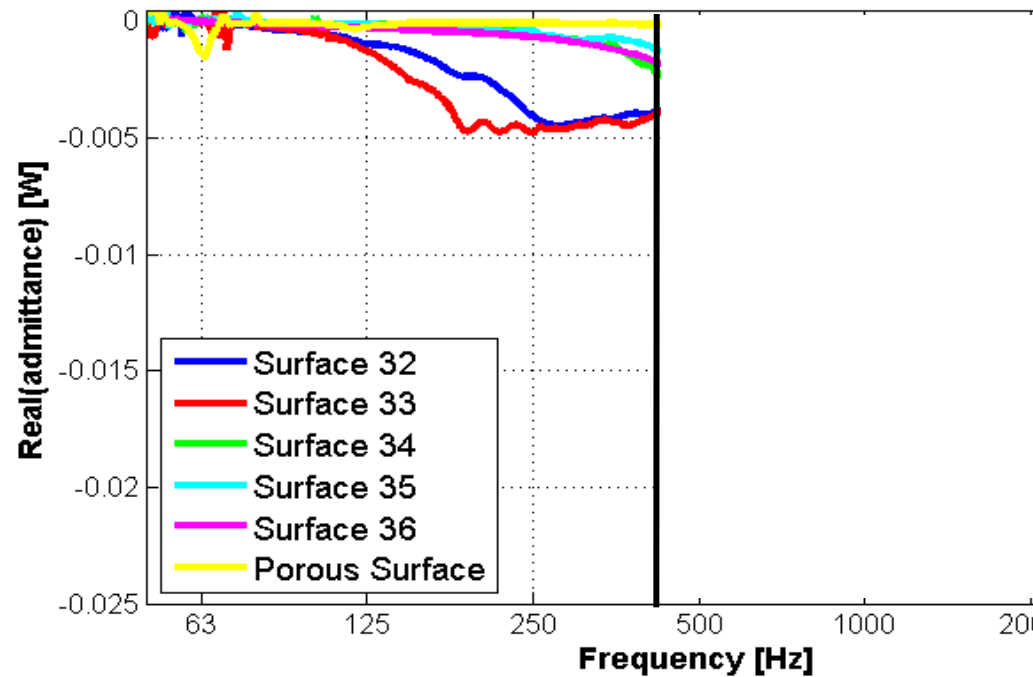
$$E = \text{Re}\{F^* X\} = \text{Re}\{A^* F^2\}$$

Rolling resistance vs. road impedance

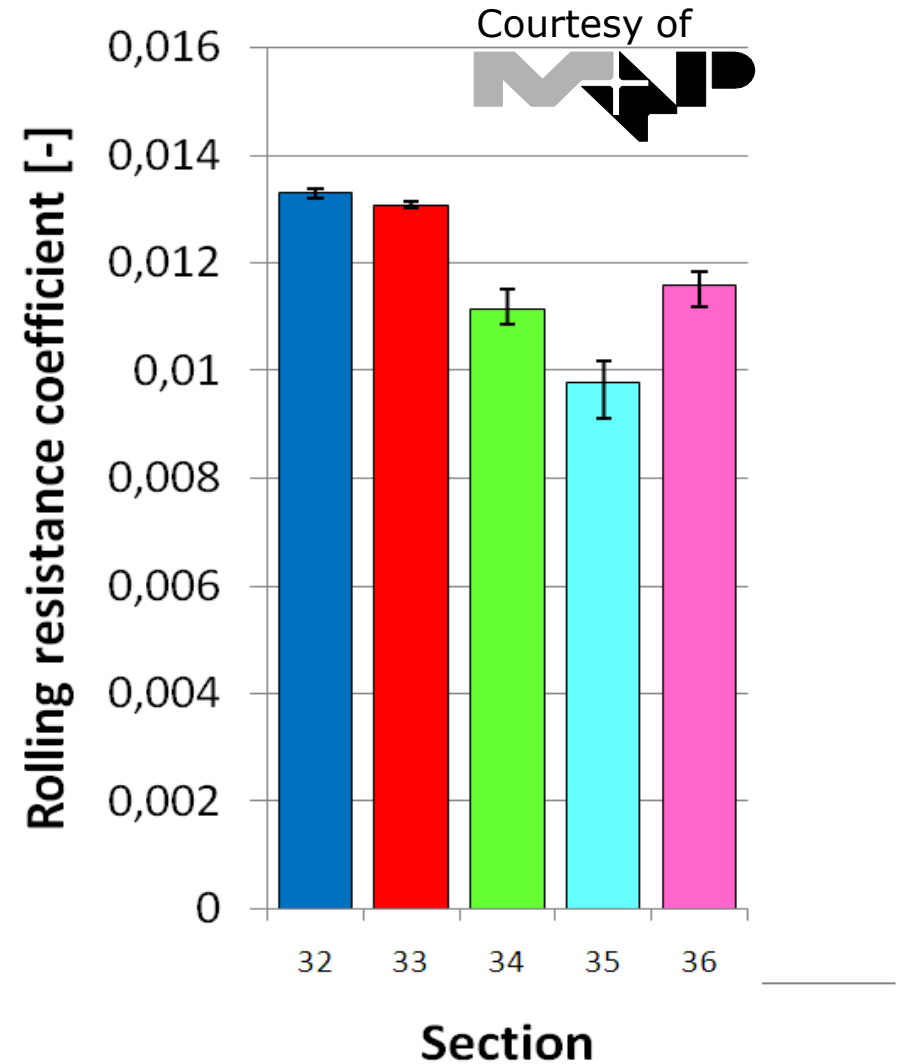


Rolling resistance & Road impedance

Real part of the admittance for a 1 N input force



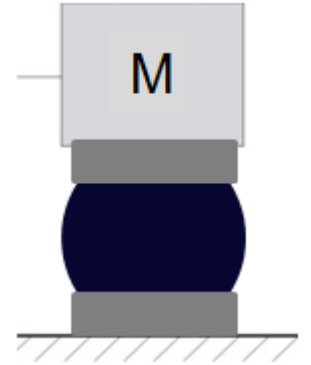
Frequencies at 80 km/h



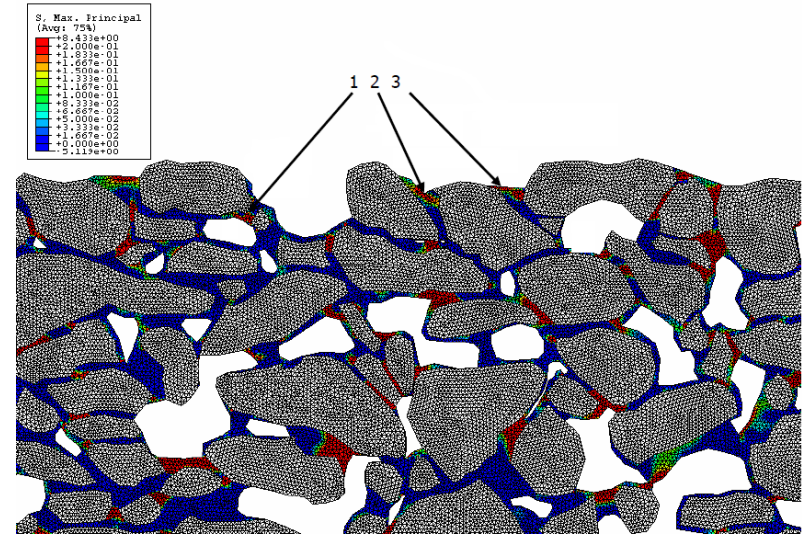
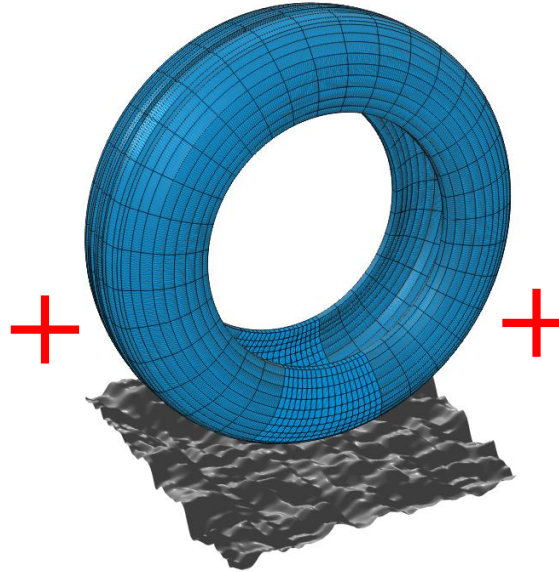
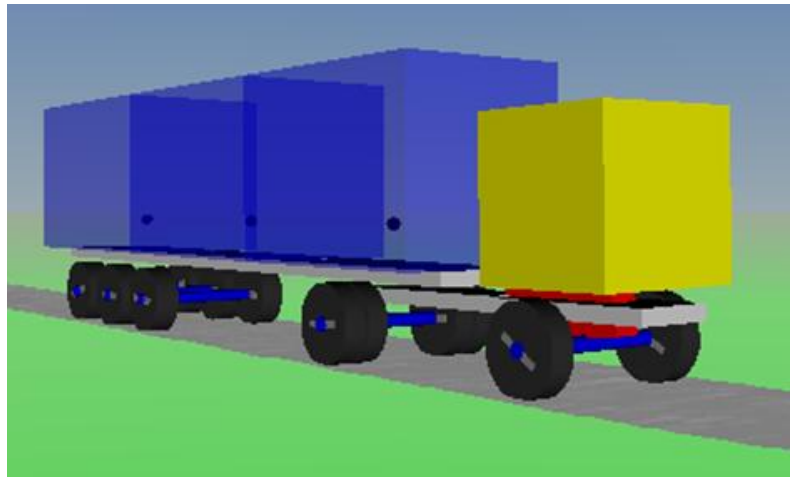
Courtesy of
MAD

Rolling resistance & Road impedance

- ... but rubberized roads are made of rubber.
- Their contribution to RR depends on:
 - Temperature: summer/winter.
 - Frequency: road texture, vehicle velocity.
 - Strain amplitude: heavy vehicles/passenger cars.



Summary



= Virtual prototyping for green road design
