The wheel/rail interaction – a primer

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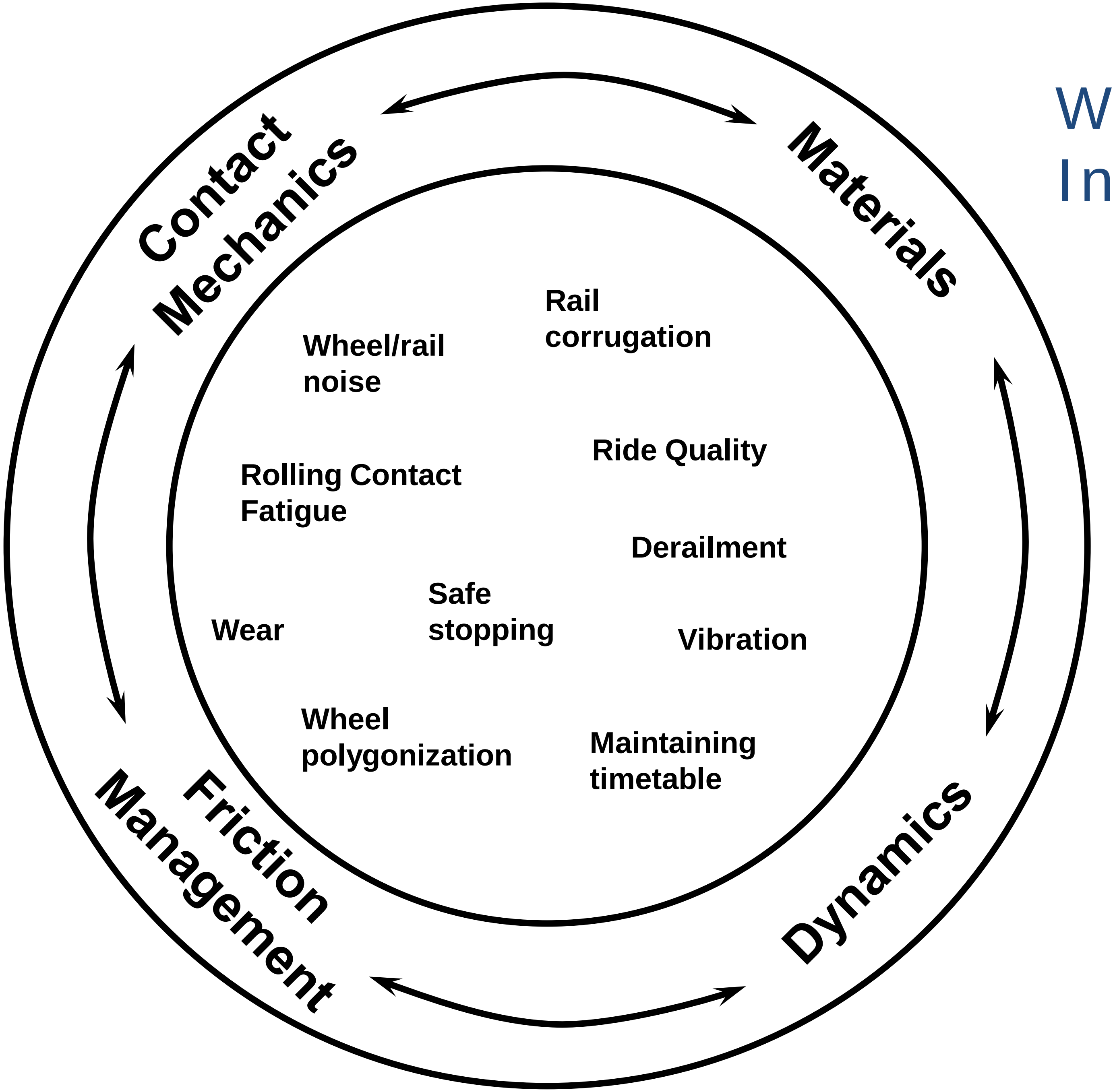
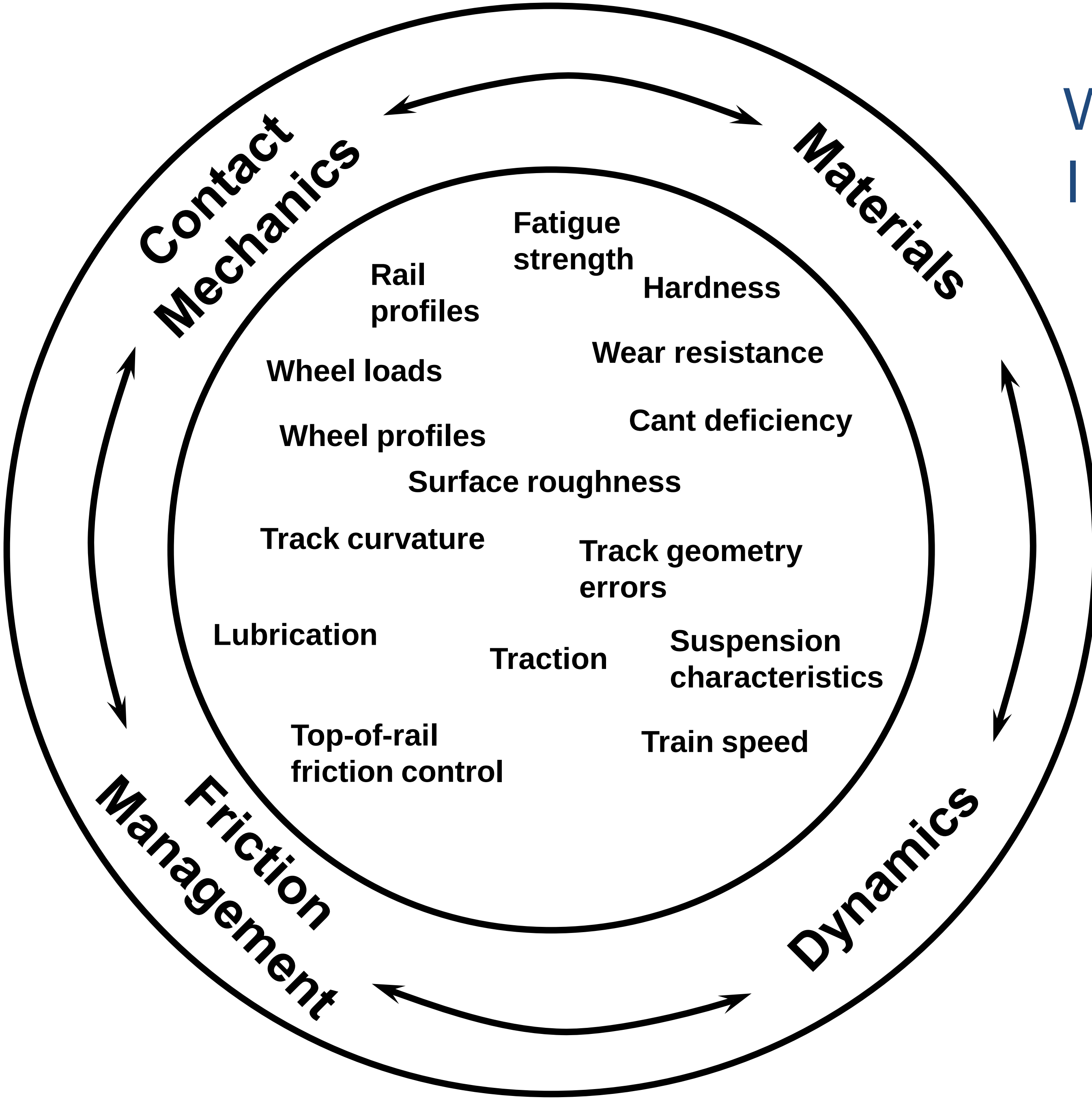
Wheel/Rail Interaction





Wheel/Rail Interaction

Outline

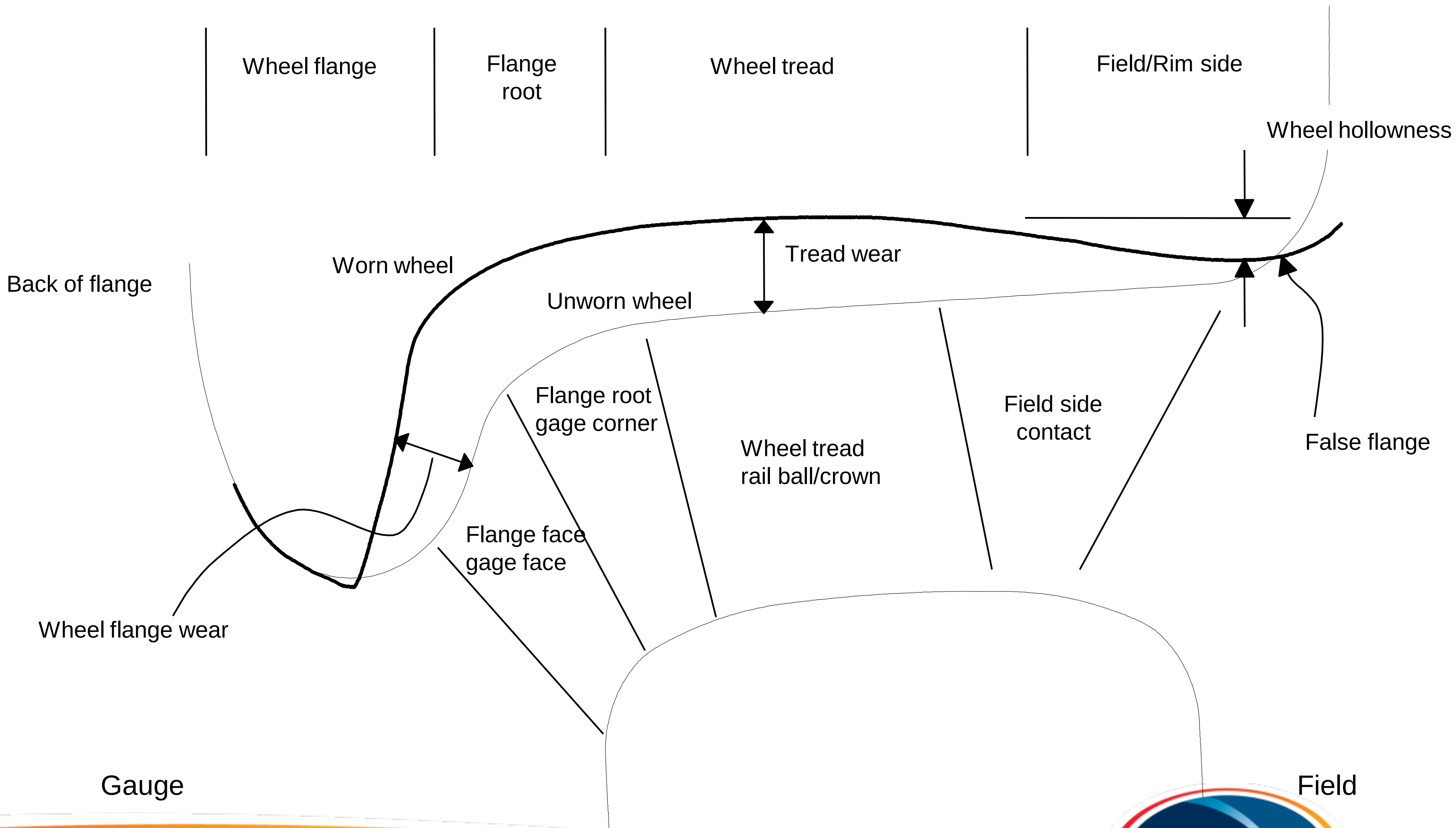
Contact mechanics

Friction management

Materials

Dynamics

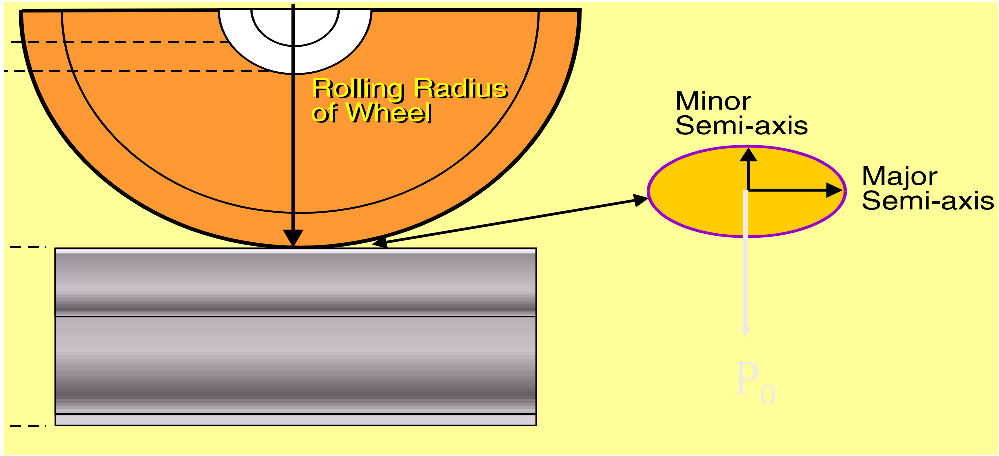
Terminology



Contact Mechanics

Hertzian Contacts

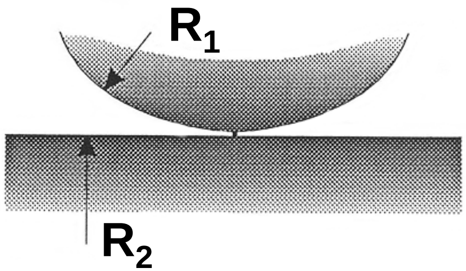
Heinrich Hertz
1857-1894



Hertzian Contacts

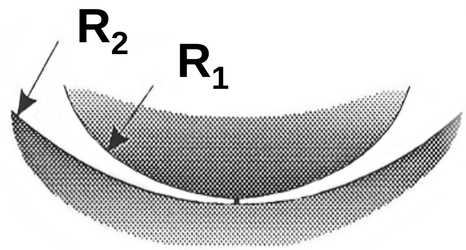
- Semi-infinite bodies
  - o area of contact small compared to size of the body and radii of curvature
- The surfaces are continuous and non-conforming
- Frictionless

Contact with flat



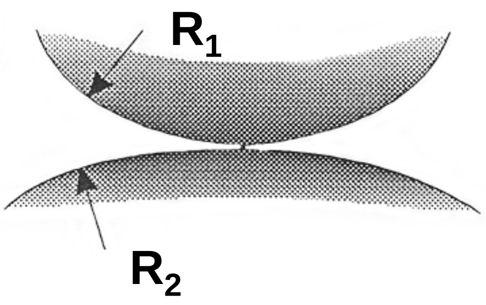
$R_1 > 0$ $R_2 = \infty$ $1 / R_2 = 0$

Conformal contact



$R_1 > 0$; $R_2 < 0$

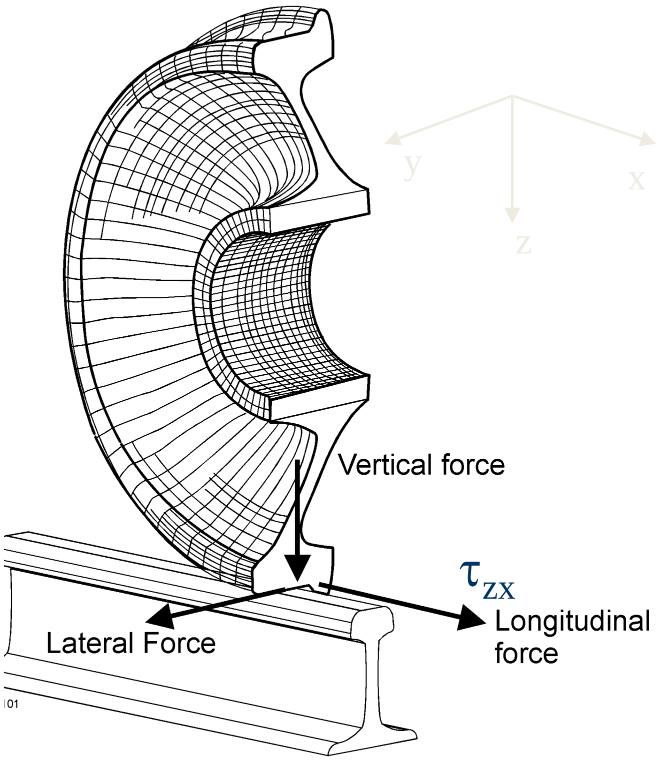
Counterformal contact



$R_1 > 0$; $R_2 > 0$

Wheel/rail stresses

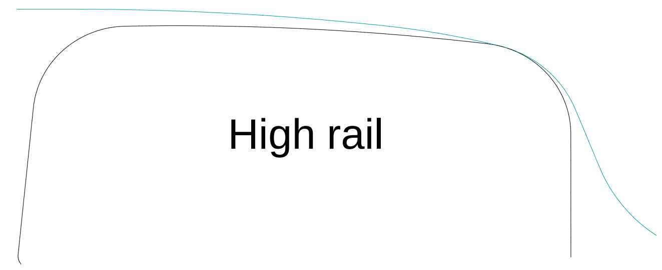
- Vertical, longitudinal, and lateral forces
- Lead to a complex stress field
  - Compressive, tensile and shear stress components
- P_0 is maximum stress in system
- Important stresses = τ_{zx}, τ_{zy}
  - The stress on the z plane in the x and y direction
  - Cause shear of rail surface



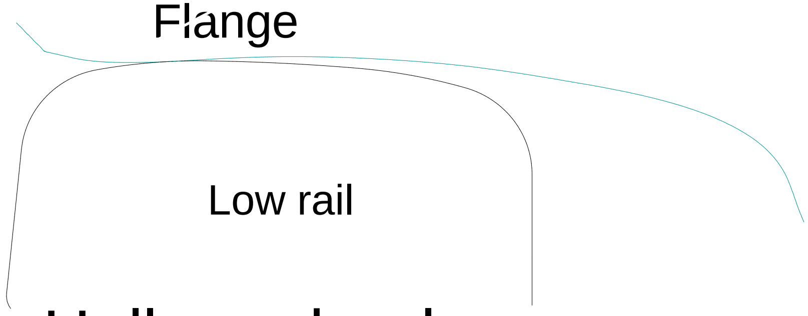
Contact Stress

Stress and damage depend on:

- wheel radius
- wheel load
- friction coefficient
- wheel/rail profiles (contact geometry)



Non-conformal contact



Hollow wheels

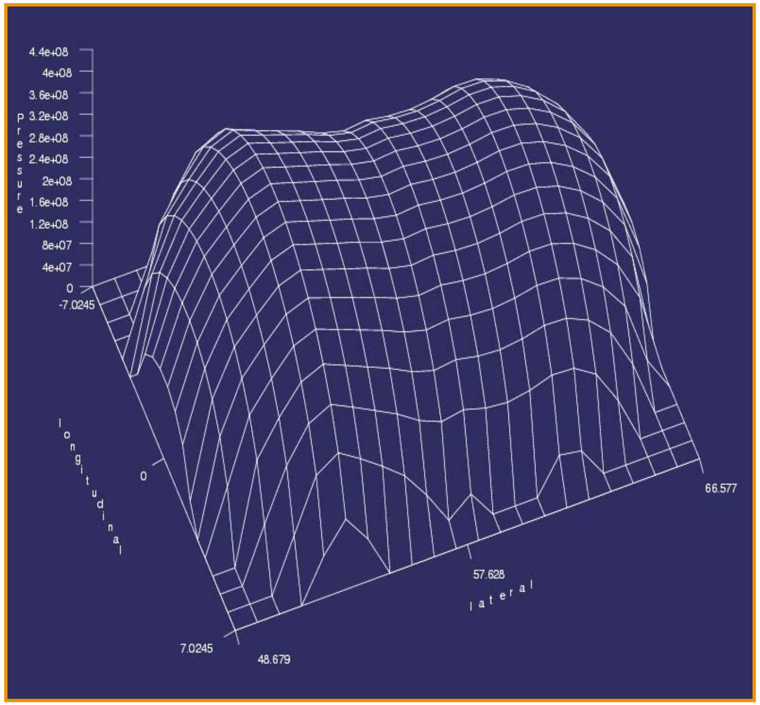
Rail / Wheel:
Hertzian Contact Stress (MPa)

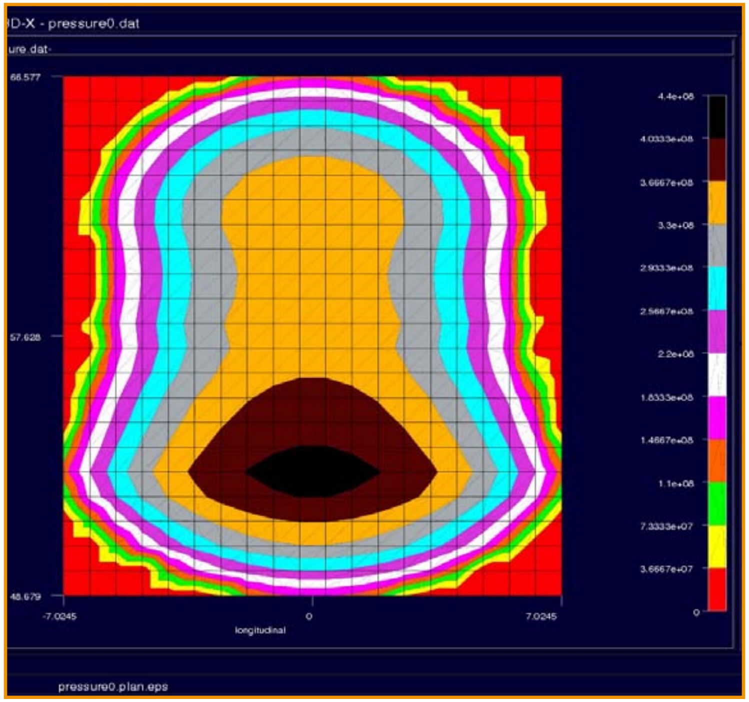
$$P_o = \left(\frac{6PE^{*2}}{\pi^3 R_e^2} \right)^{1/3} \times \left[\quad F_1 (R_L / R_T)^{-2/3} \quad \right]$$

spherical contacts accounts for ellipticity

LOCATION	Transverse Radius		Load, Wheel Radius					
	Rail [mm]	Wheel [mm]	18 tonnes, 480 mm		18 tonnes, 240 mm		9 tonnes, 240 mm	
Rail Crown	+200	-300	1130	(1.00)	1438	(1.27)	1141	(1.01)
	+75	-100	1428	(1.26)	1794	(1.59)	1424	(1.26)
	+100	-300	1819	(1.61)	2267	(2.01)	1800	(1.59)
	+200	infinity	1645	(1.46)	2053	(1.82)	1629	(1.44)
Rail Shoulder	+32	-38	1637	(1.45)	2043	(1.81)	1622	(1.44)
	+32	-44	1984	(1.76)	2469	(2.18)	1960	(1.73)
Flange Root	+8	-9.5	2678	(2.37)	3317	(2.94)	2632	(2.33)
False Flange	+300	+50	2845	(2.52)	3520	(3.12)	2794	(2.47)

Most contacts are non-Hertzian

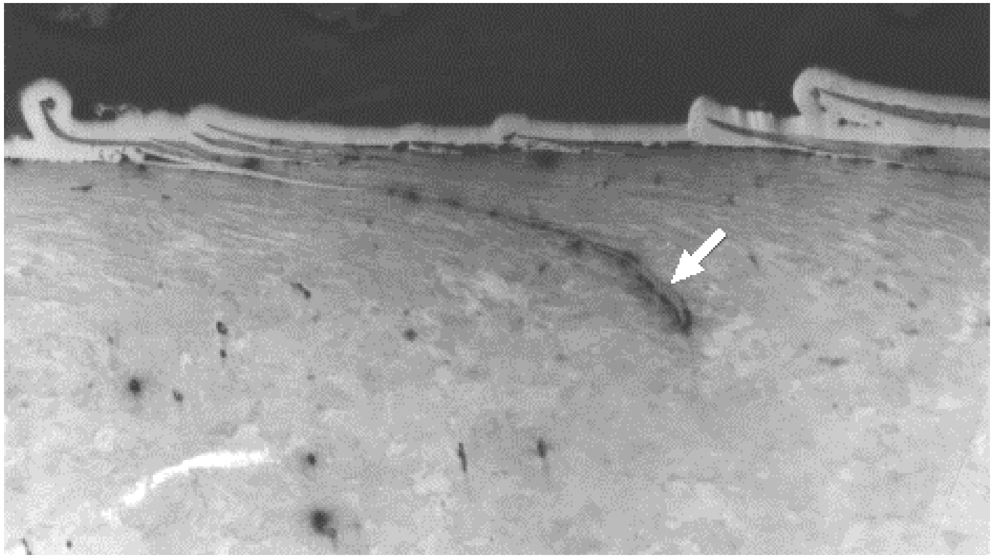




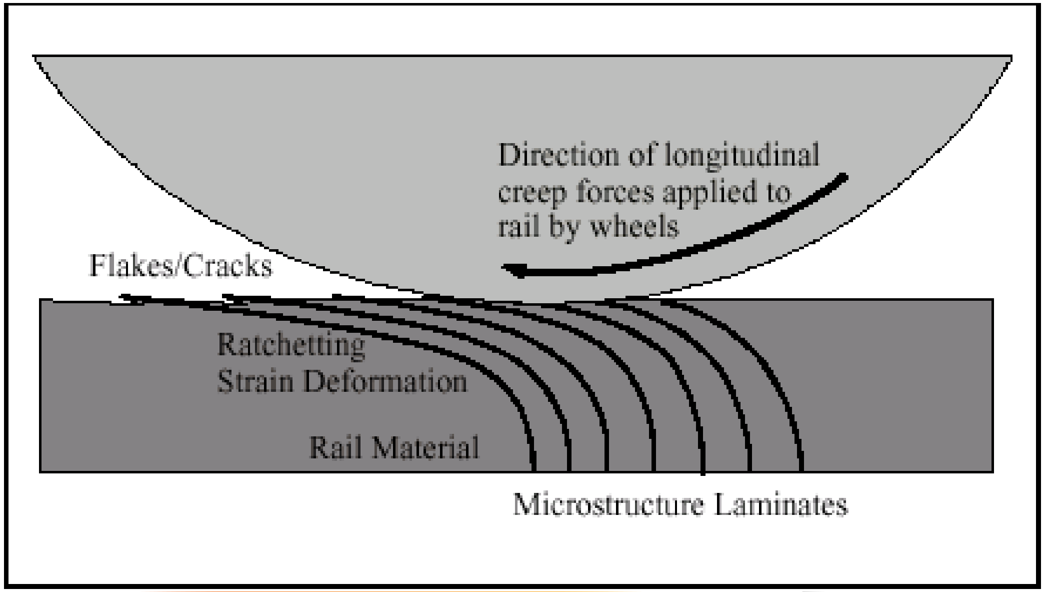
Generally Hertzian assumption is not too bad: ±20%

Friction (Management)

Effect of friction



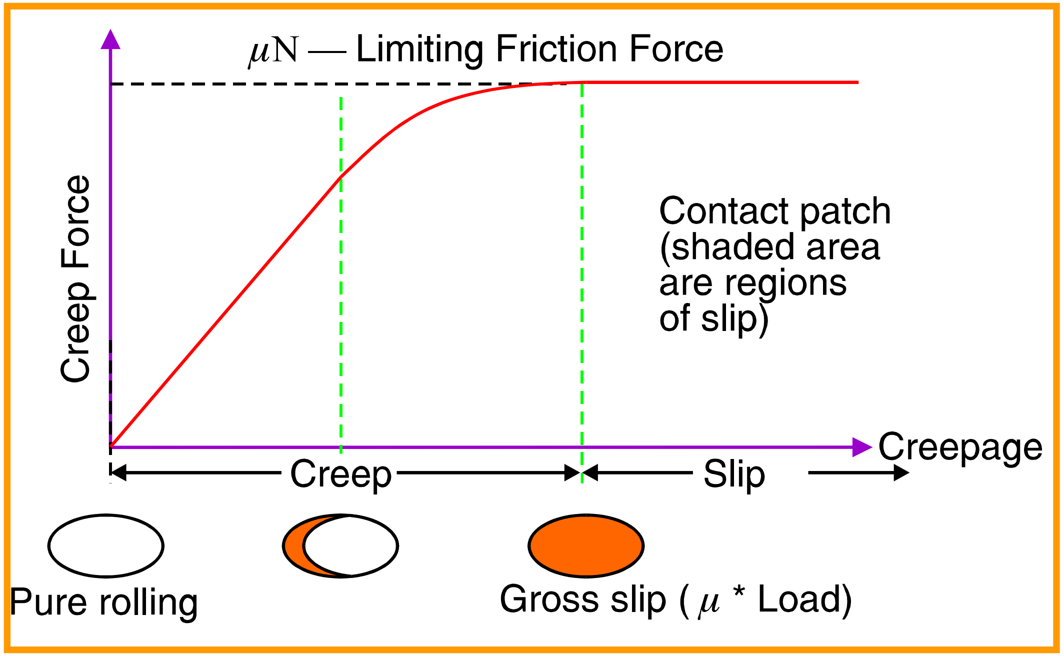
Rolling Direction



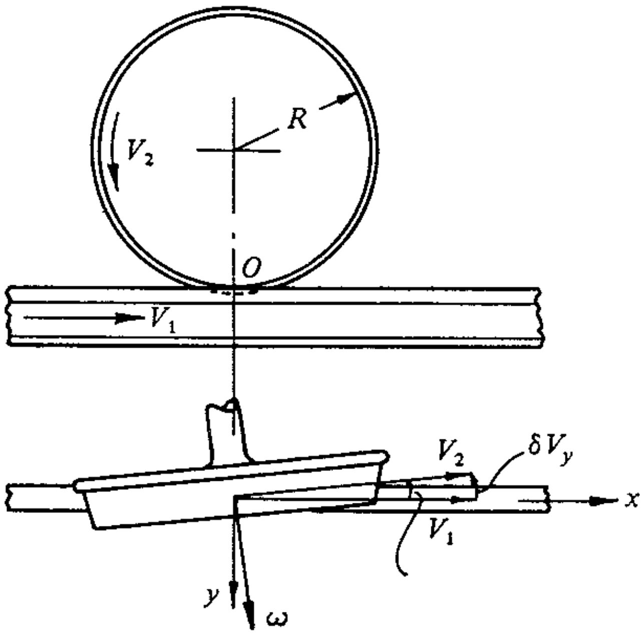
Slip - creepage

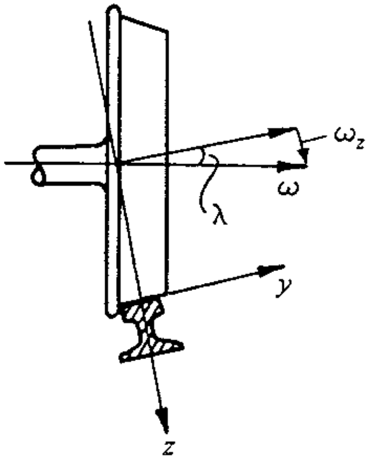
Creep: Elastic deformation of the wheel and rail material in the vicinity of the contact patch

- **Longitudinal creep – wheels have different rolling radii, or braking or acceleration**
- **Lateral creep – wheelset has angle-of-attack**
- **Spin creep also present**
- **Creep leads to creep forces (and spin moment)**
  - **Fundamental steering forces**



Creepage in a single wheel/rail contact





Longitudinal Creepage

$$\psi_X = \frac{V_2 - V_1}{V_1}$$

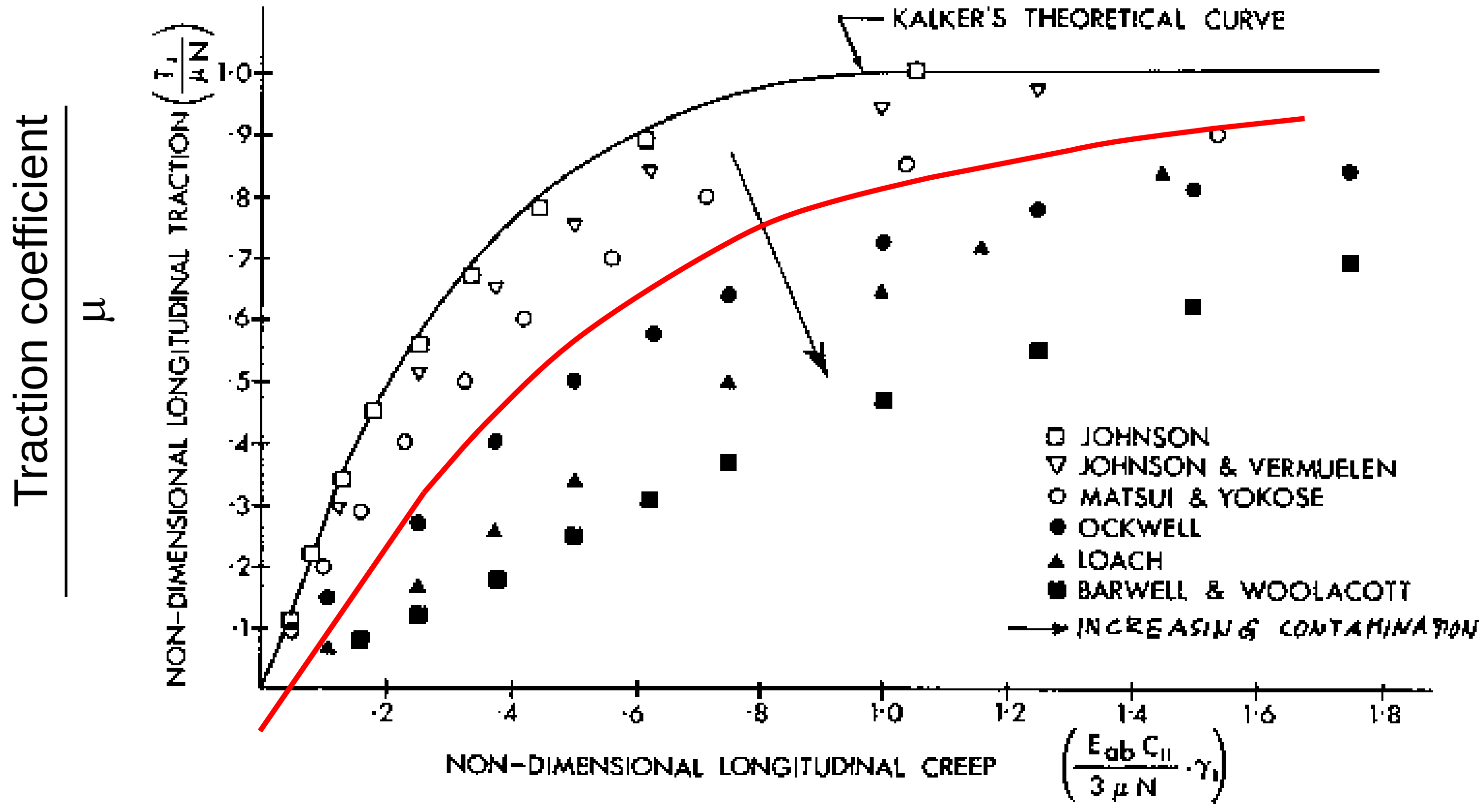
Lateral Creepage

$$\psi_Y = \frac{\delta V_Y}{V_1} = \tan\gamma$$

Spin Parameter

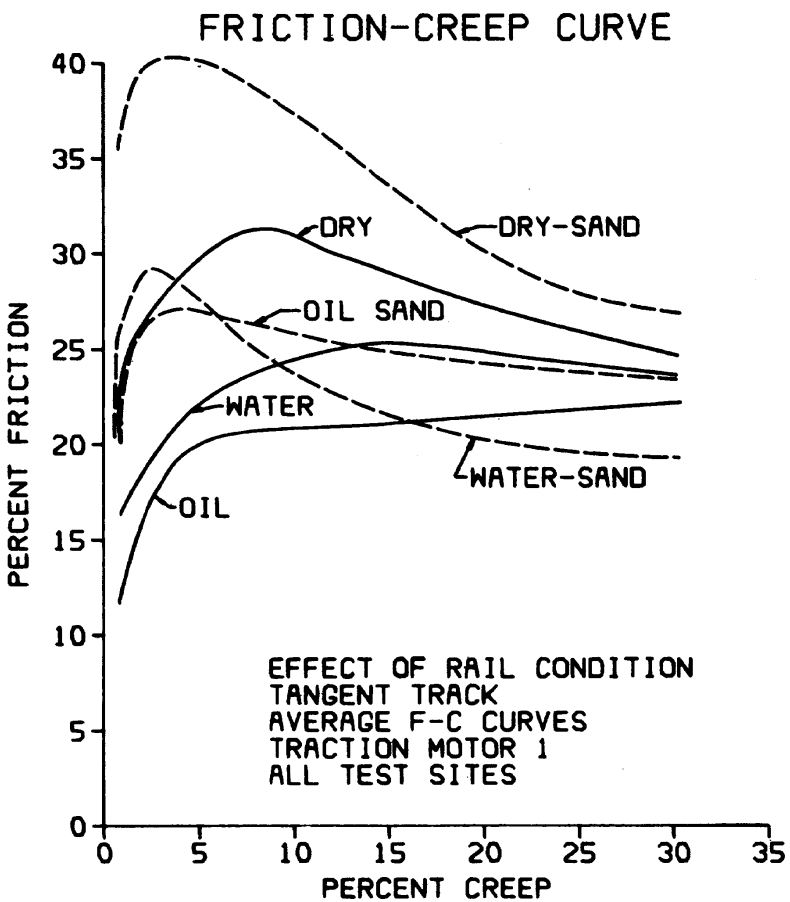
$$\Phi = \omega \frac{(ab)^{1/2}}{V_1 R} = \left(\frac{(ab)^{1/2}}{R}\right)\tan\lambda$$

Friction



Traction coefficient
μ
NON-DIMENSIONAL LONGITUDINAL TRACTION
KALKER'S THEORETICAL CURVE
JOHNSON
JOHNSON & VERMUELEN
MATSUI & YOKOSE
OCKWELL
LOACH
BARWELL & WOOLACOTT
INCREASING CONTAMINATION
NON-DIMENSIONAL LONGITUDINAL CREEP

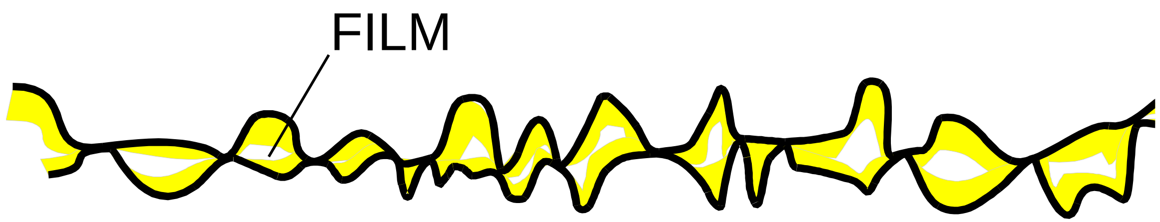
Wheel/rail traction-creepage curve (field tests)



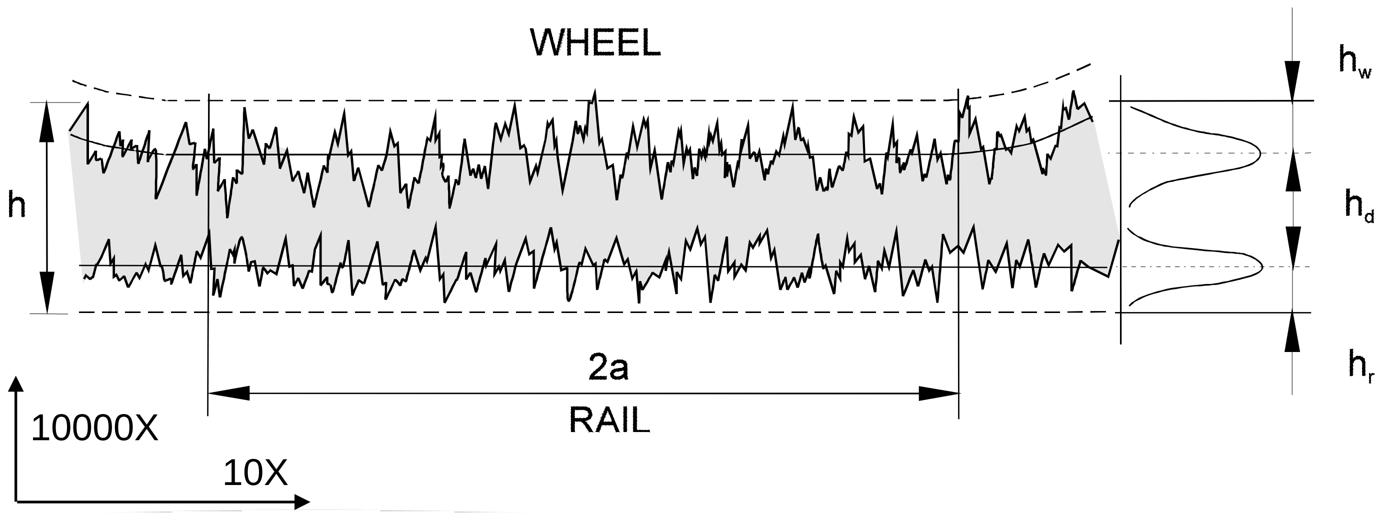
Field Tests

(Logston & Itami 1980)

Third-body layer

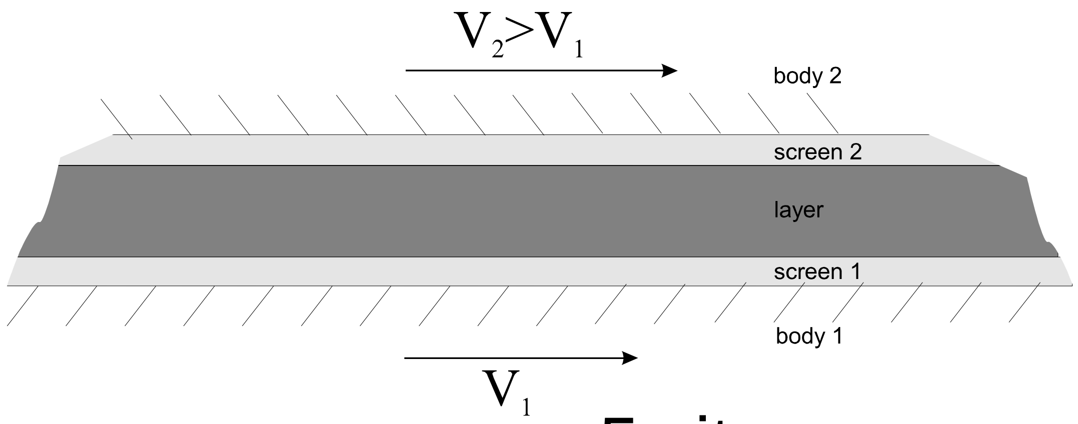


- Petrochemical:
oil, soap, grease
- Solid / mechanical:
moly, graphite
- Chemical:
phosphate, salts, etc.



LAYERS:
Any microscopic mixture of solid and semi-solid particles

Third-body velocity accommodation mechanism



(After Godet)

4 modes

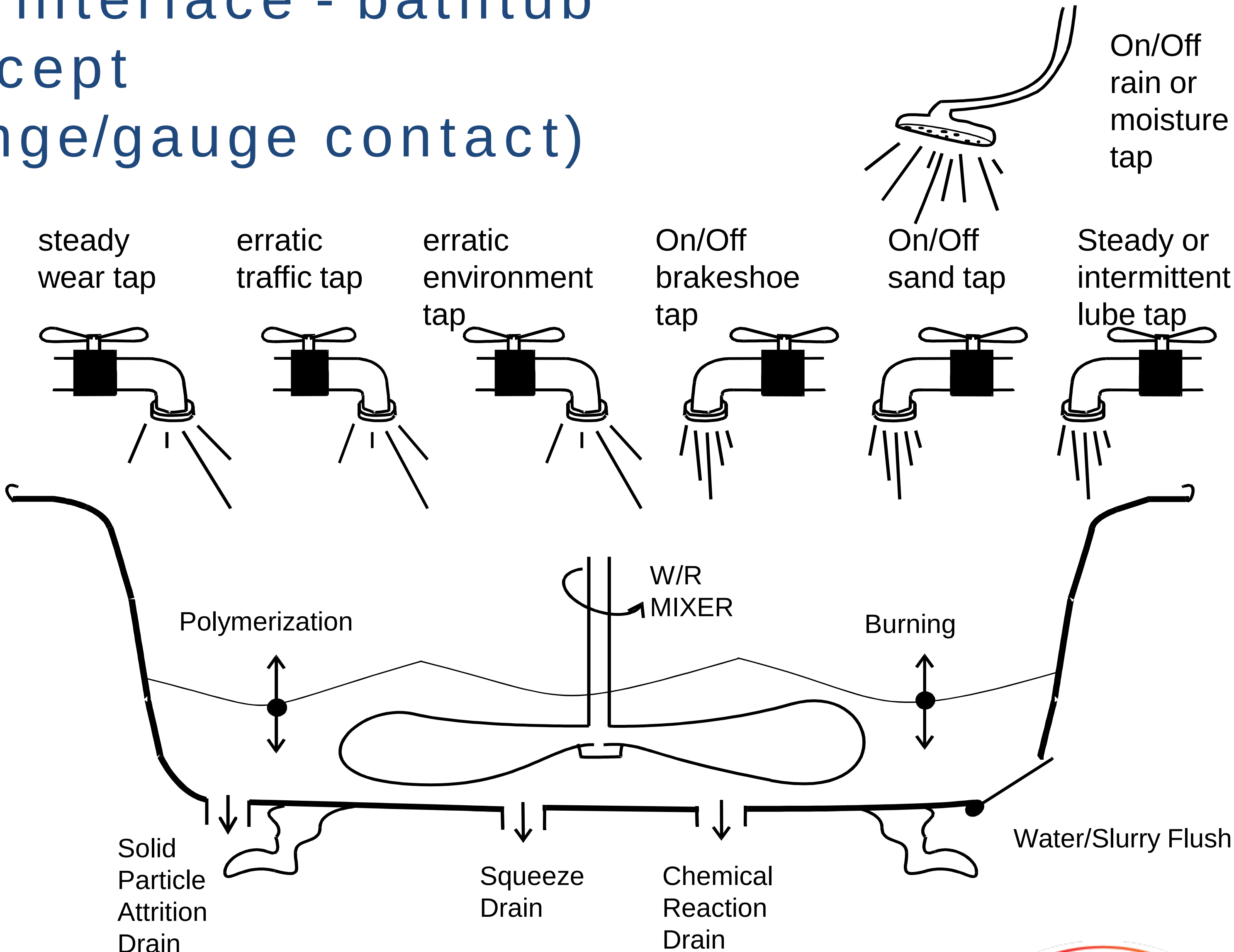
- elastic deformation
- normal breaking
- shearing
- rolling

5 sites

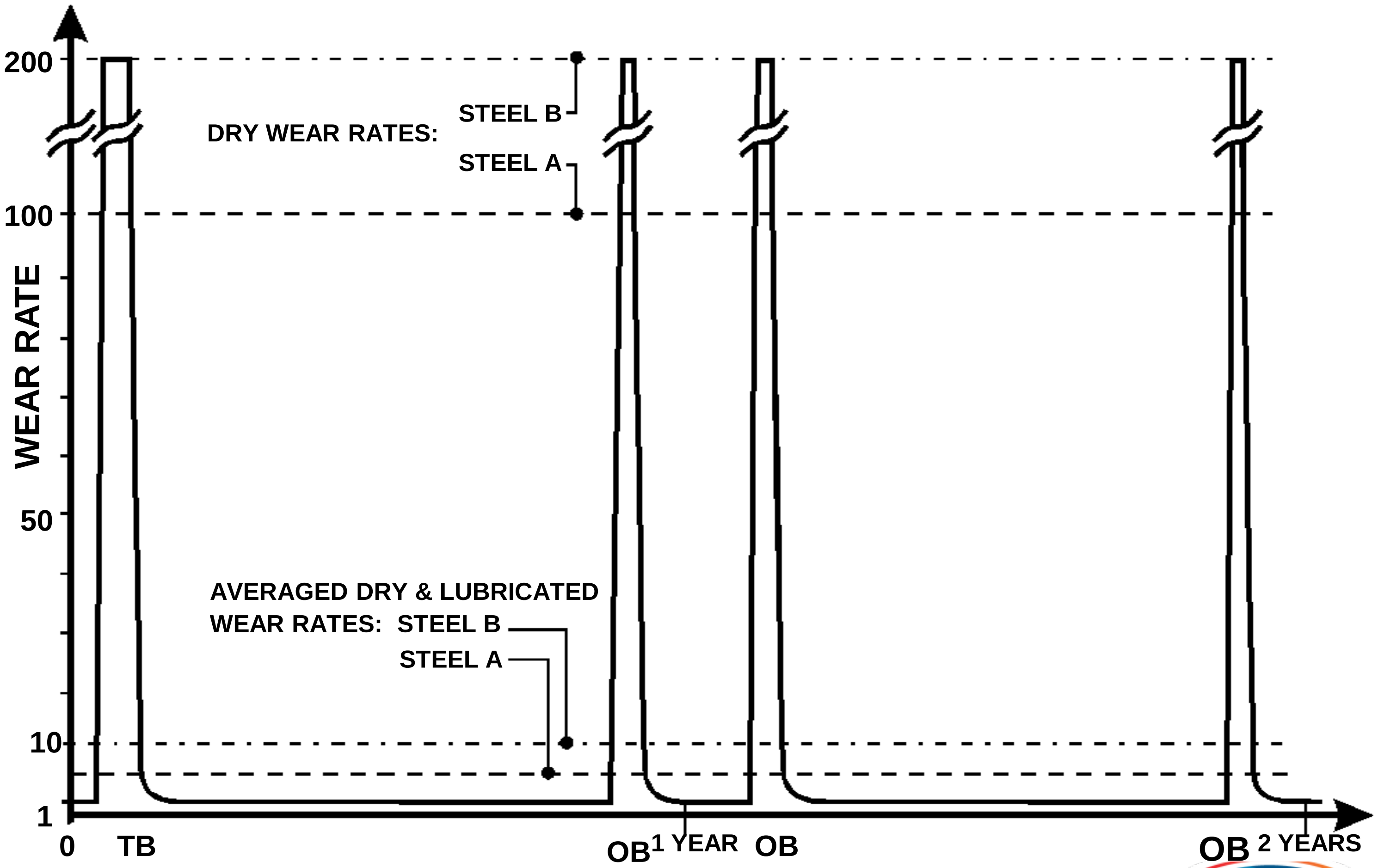
- body 1
- screen 1
- layer (third body)
- screen 2
- body 2

4 x 5 = 20 possible velocity accommodation mechanisms

W/R interface - bathtub concept (flange/gauge contact)

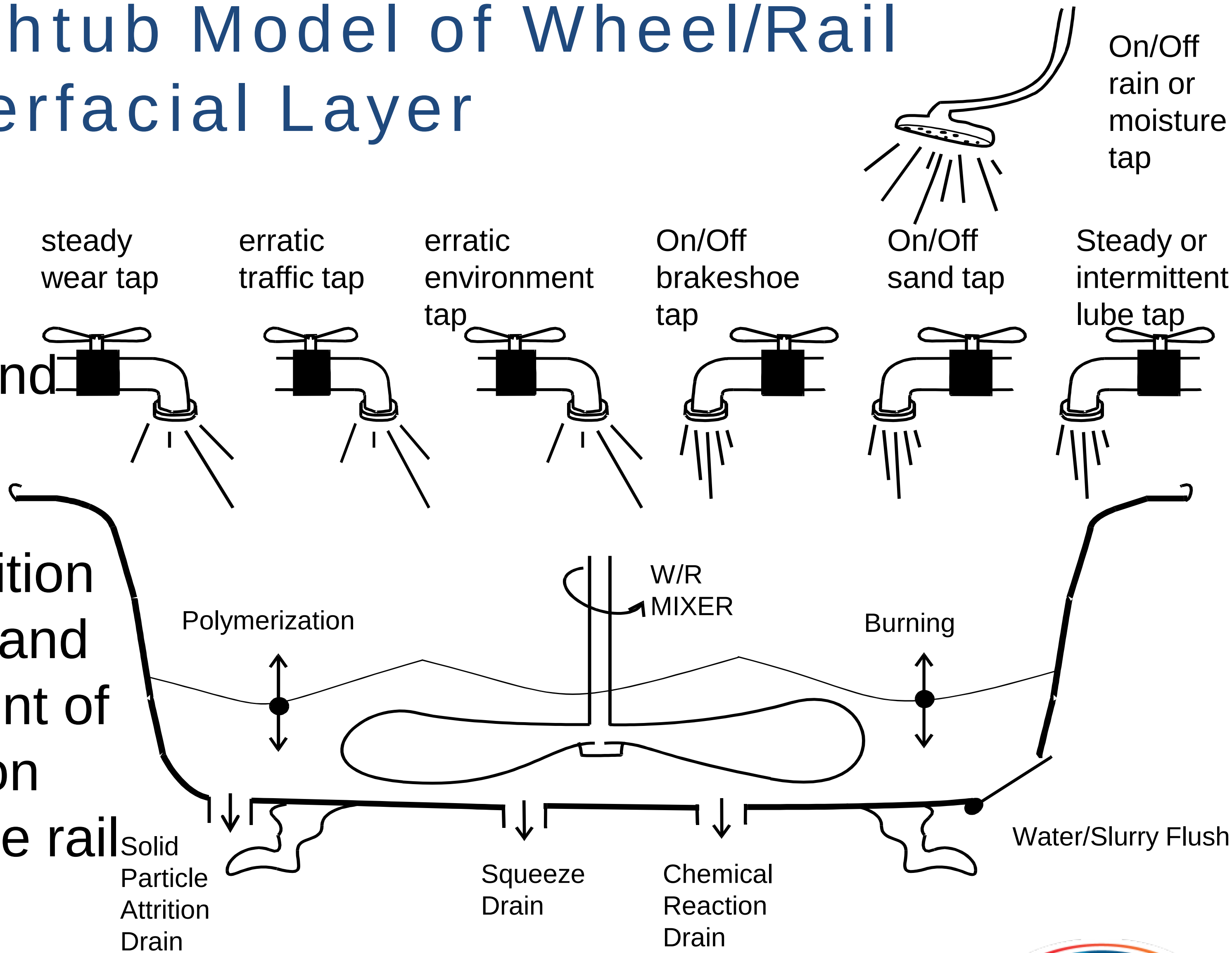


Keep the lubrication tap on at all times!

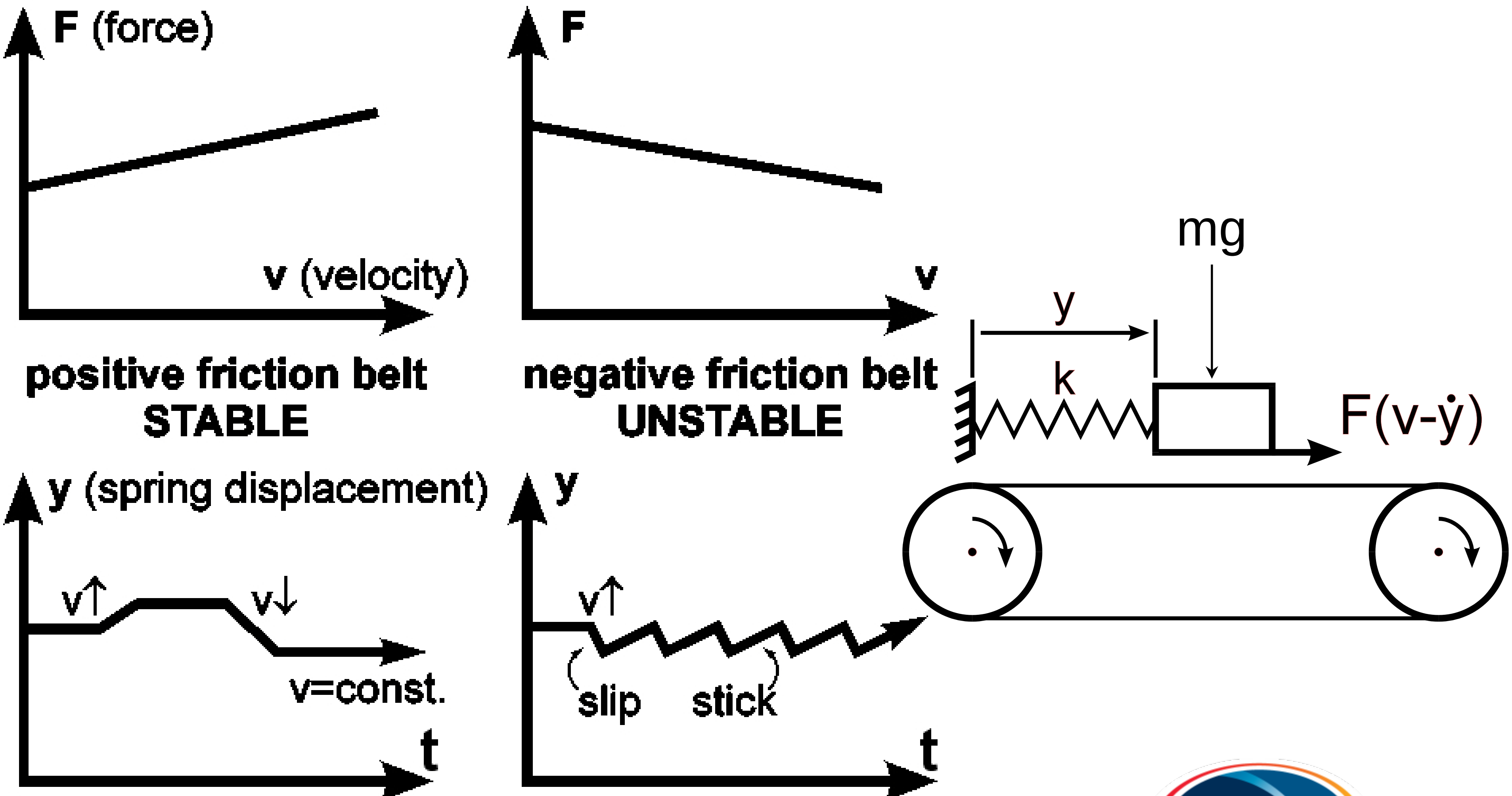


Bathtub Model of Wheel/Rail Interfacial Layer

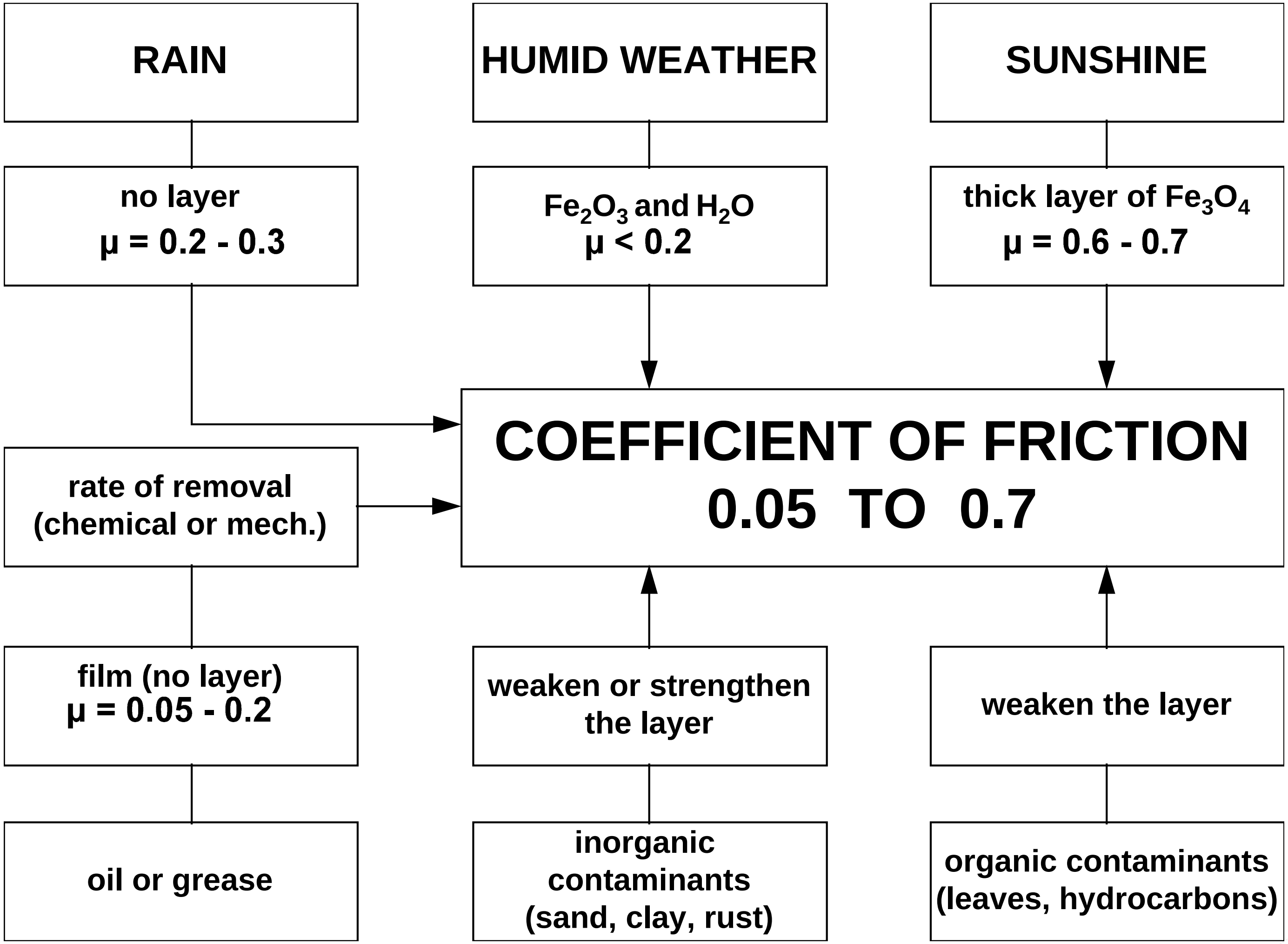
Inputs and outputs govern composition of layer and coefficient of friction on top of the rail



Stick-Slip - The prony brake



Friction – highly variable



Controlling W/R Friction
2 zones of concern

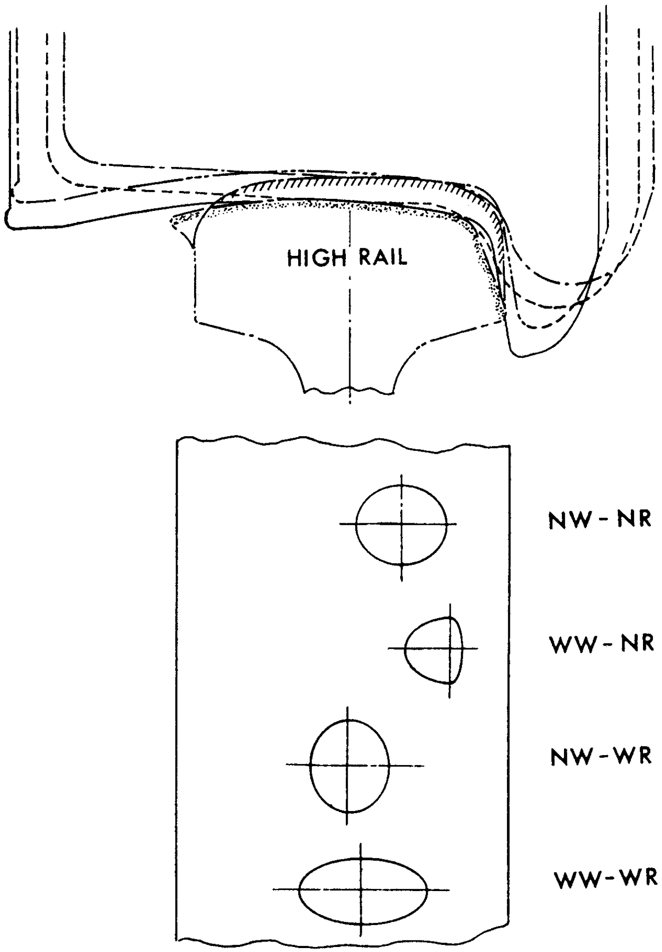
Materials

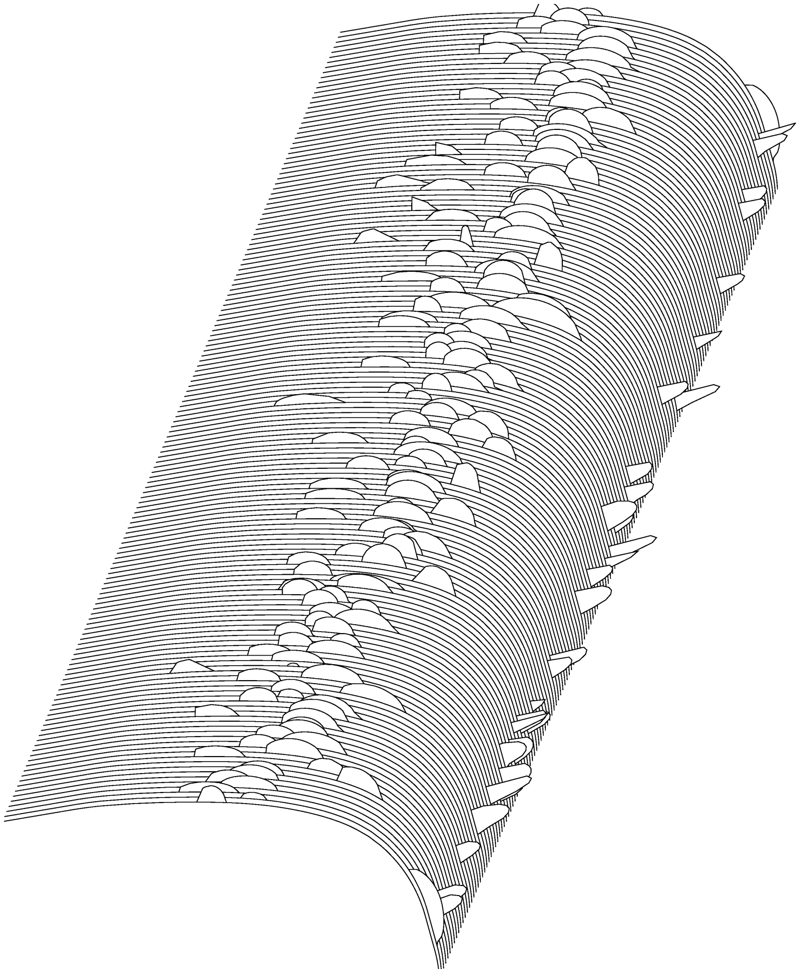
Materials

- Hardness – resistance to plastic flow
- Toughness – resistance to crack propagation
- Cleanliness – reduced internal defects
- Metallurgy
  - Pearlitic – good fatigue and wear resistance
  - Bainitic – better resistance to fatigue but tends to wear higher

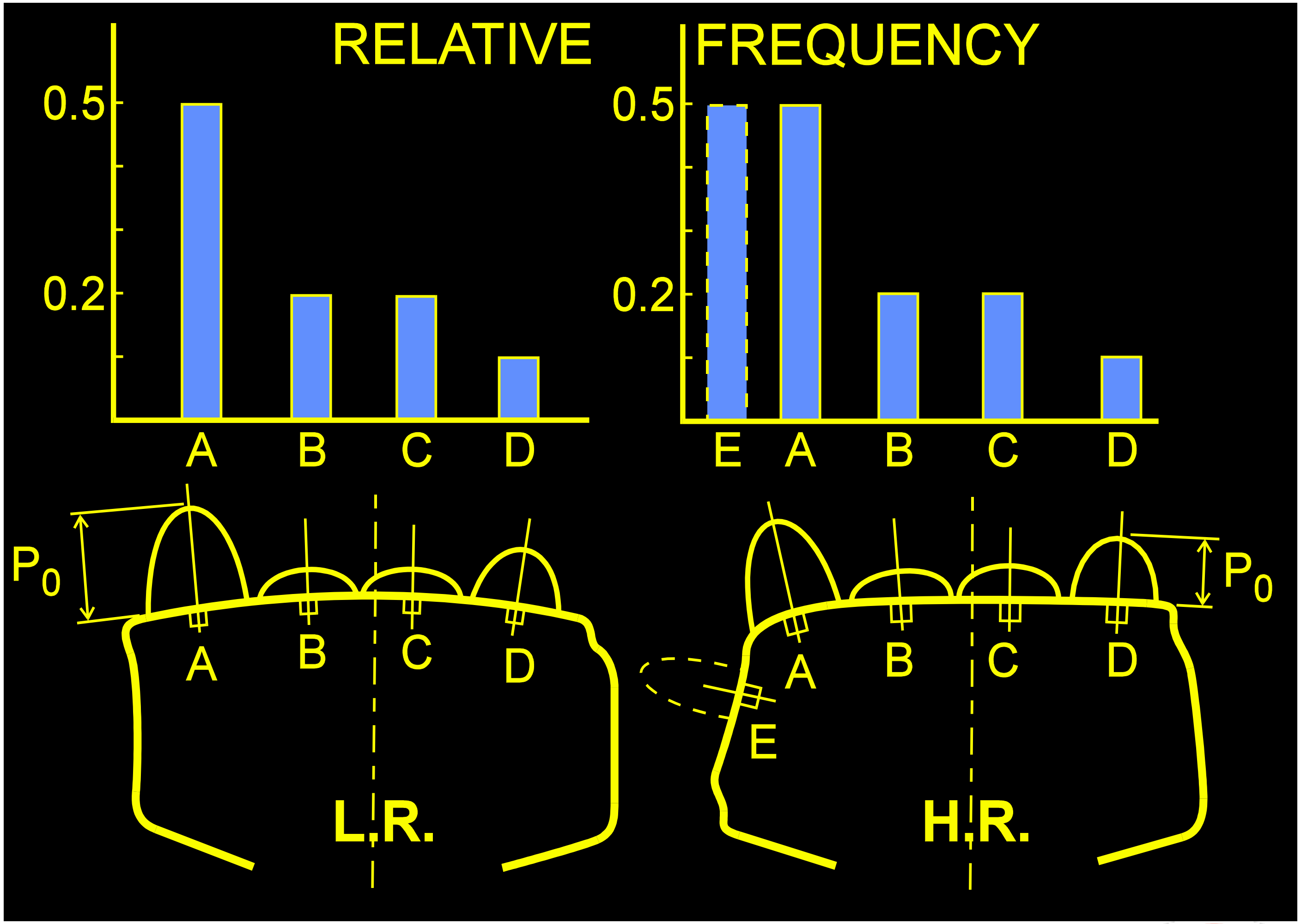
Dynamics

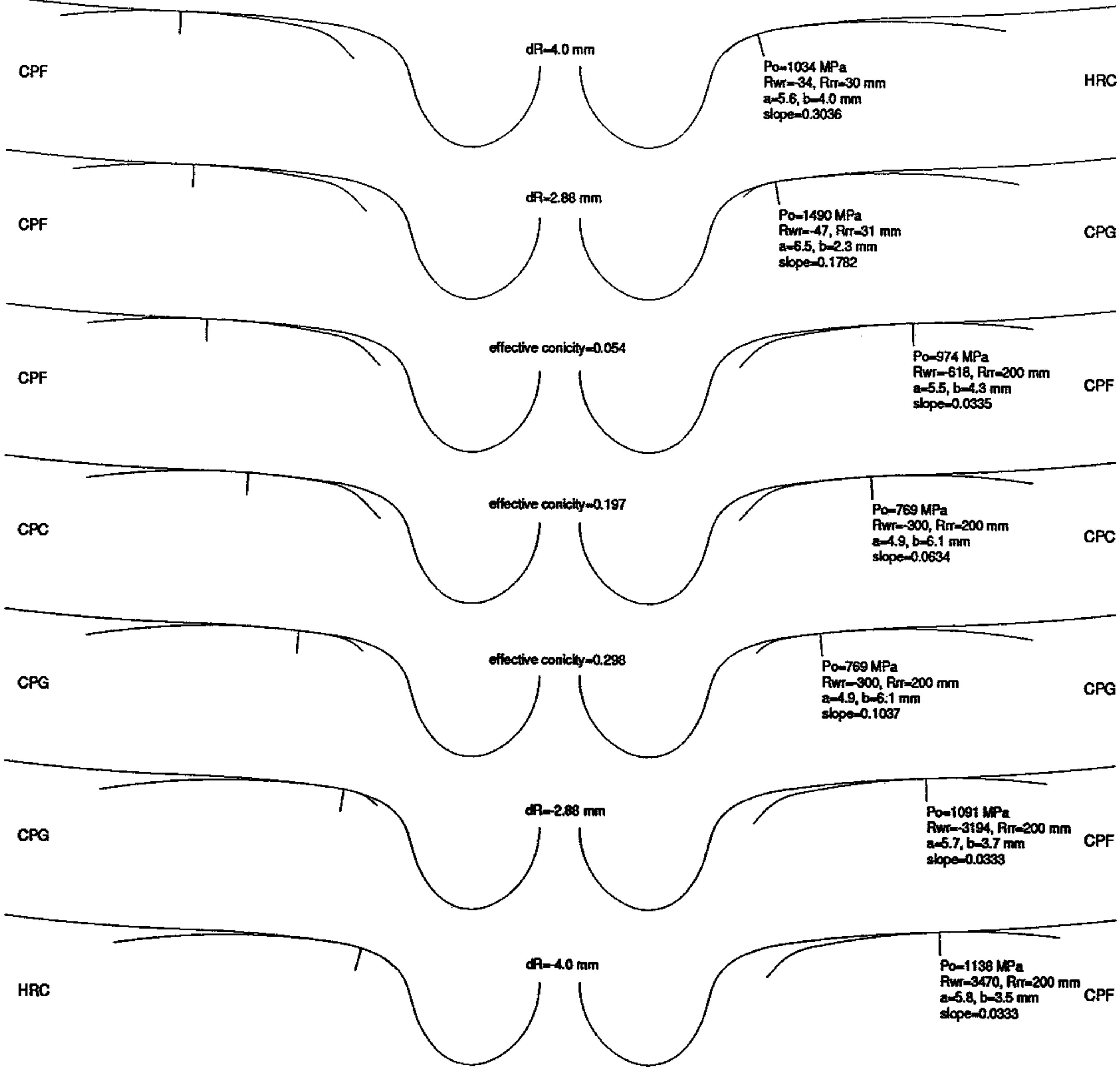
Pummelling



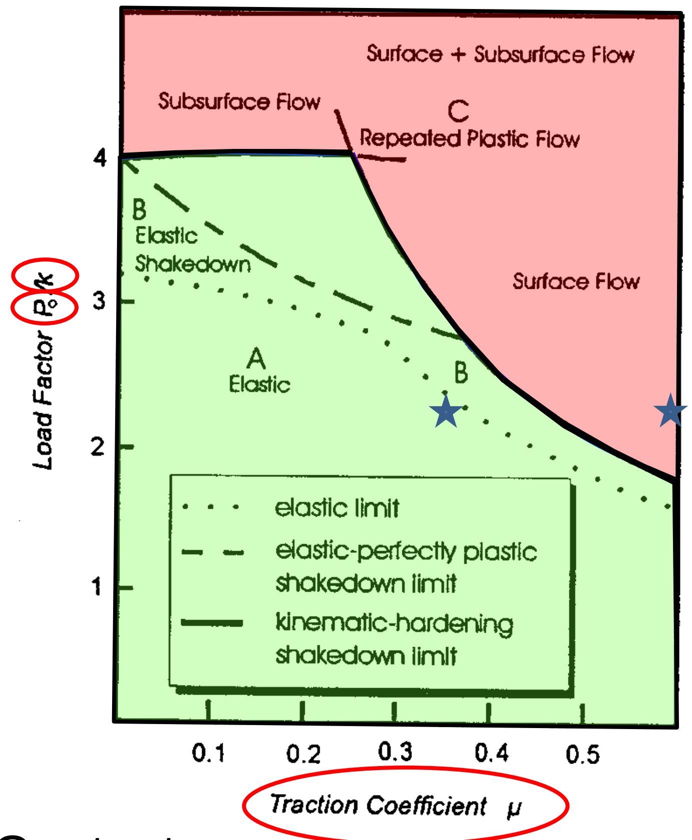


Rail Profile Design - Pummelling

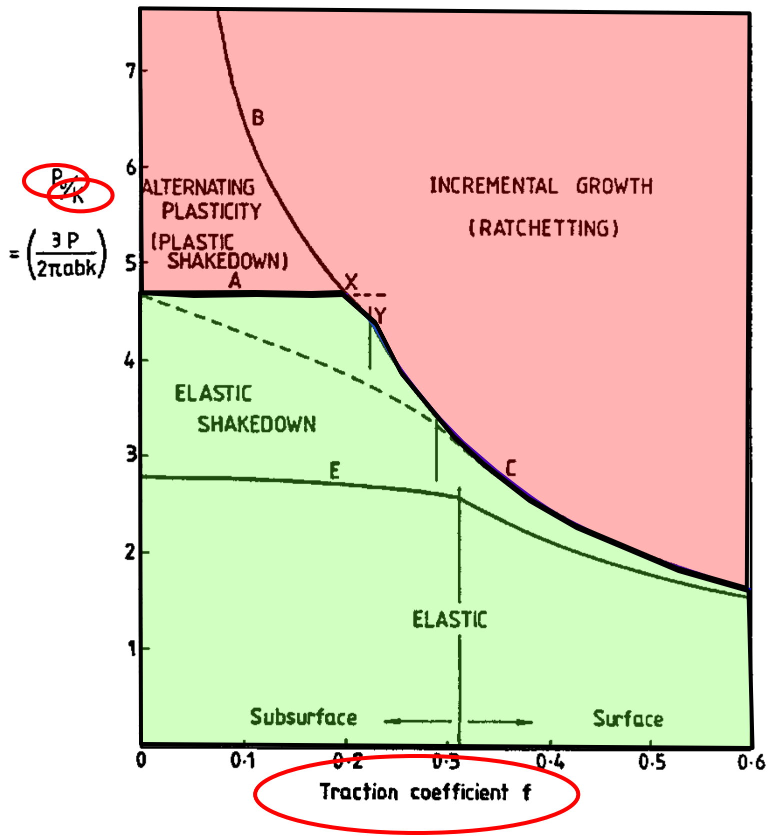



CPF
dR=4.0 mm
Po=1034 MPa
Rwr=-34, Rrr=30 mm
a=5.6, b=4.0 mm
slope=0.3036
HRC
CPF
dR=2.88 mm
Po=1490 MPa
Rwr=-47, Rrr=31 mm
a=6.5, b=2.3 mm
slope=0.1782
CPG
CPF
effective conicity=0.054
Po=974 MPa
Rwr=-618, Rrr=200 mm
a=5.5, b=4.3 mm
slope=0.0335
CPF
CPC
effective conicity=0.197
Po=769 MPa
Rwr=-300, Rrr=200 mm
a=4.9, b=6.1 mm
slope=0.0634
CPC
CPG
effective conicity=0.298
Po=769 MPa
Rwr=-300, Rrr=200 mm
a=4.9, b=6.1 mm
slope=0.1037
CPG
CPG
dR=-2.88 mm
Po=1091 MPa
Rwr=-3194, Rrr=200 mm
a=5.7, b=3.7 mm
slope=0.0333
CPF
HRC
dR=-4.0 mm
Po=1138 MPa
Rwr=-3470, Rrr=200 mm
a=5.8, b=3.5 mm
slope=0.0333
CPF

Shakedown



Line Contacts



Point Contacts

Rail / Wheel: Hertzian Contact Stress (MPa)

$$P_o = \left(\frac{6PE^{*2}}{\pi^3 R_e^2} \right)^{1/3} \times \left[\quad F_1 (R_L / R_T)^{-2/3} \quad \right]$$

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Contact Mechanics – What do we know ?

- Transverse radii of wheel and rail profiles control contact stress
- Friction raises the stress levels considerably
- Stick and slip regions in the contact patch
- The wheel most always slips on the rail

Friction Management – What do we know ?

- Friction is controlled by the characteristics of the interfacial layer
- Negative friction $\rightarrow$ stick-slip
- Bathtub model - friction control must overcome all the “natural” taps and drains in a system.

Materials –
What do we know ?

Harder
Tougher
Cleaner

Better performance

Consider the cost/benefit to determine if the best performance is needed

Dynamics –
What do we know ?

- Modelling of contact patch size, location and stresses
- Pummelling: manipulating the *distribution* of contacts for favourable distribution of wear and fatigue
- Optimizes the steady-state performance
  - o Contact stress, steering
    - – Wear
    - – Fatigue Performance

Questions ?