Dynamic Rollers in Earthworks: Compaction and Continuous Compaction Control

Johannes Pistrol[1], Dietmar Adam[1]

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Roller Compaction

1. **Static** rollers

2. **Dynamic** rollers

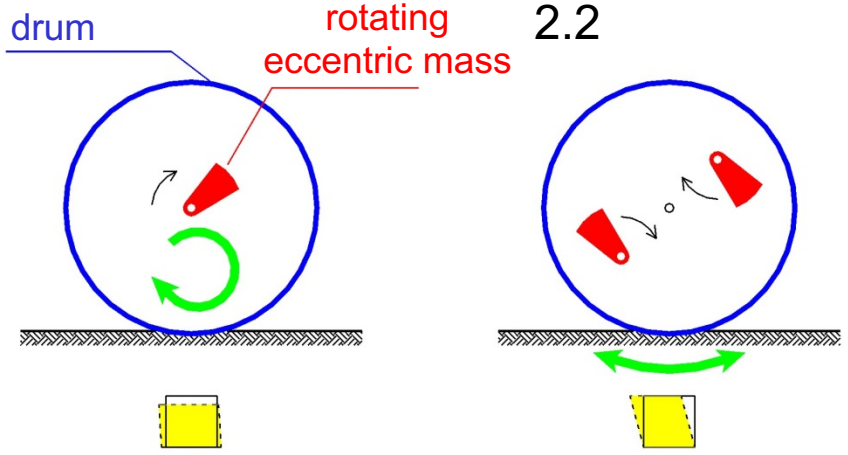
   2.1 **Vibratory** rollers

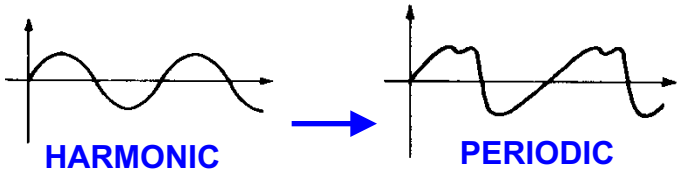
   2.2 **Oscillatory** rollers

   2.3 Rollers with **control of vertical centrifugal force**

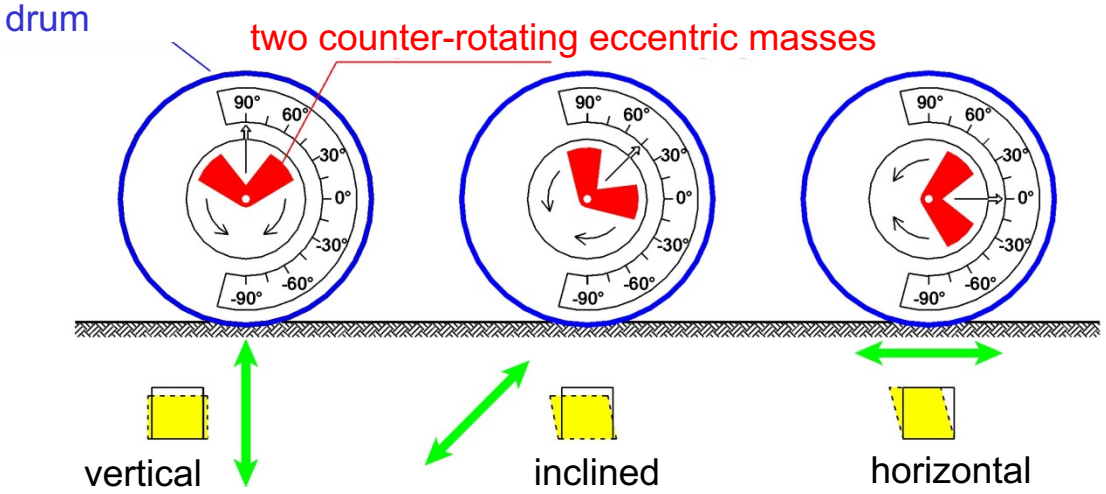
   2.4 **Feedback controlled** rollers (VARIOCONTROL, VARIOMATIC, ACE)

2.1





2.3 & 2.4

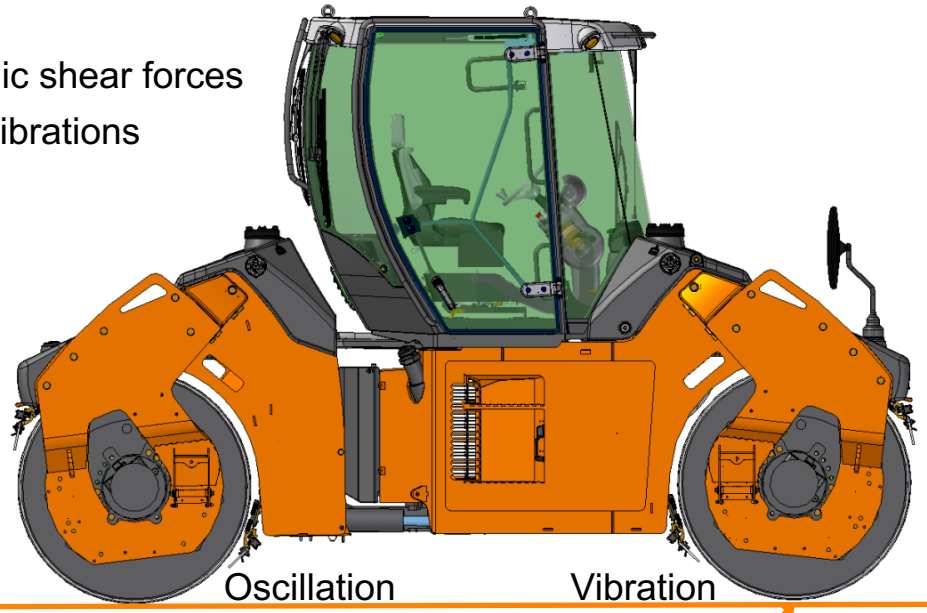


Oscillating rollers:

- two eccentric masses – eccentric but point symmetric to the drum axis
- same sense of rotation
  ⇒ sinusoidal torque around drum axis
- mainly dynamic shear forces
- low ambient vibrations

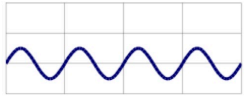
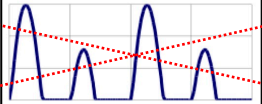
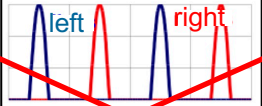
Vibrating rollers:

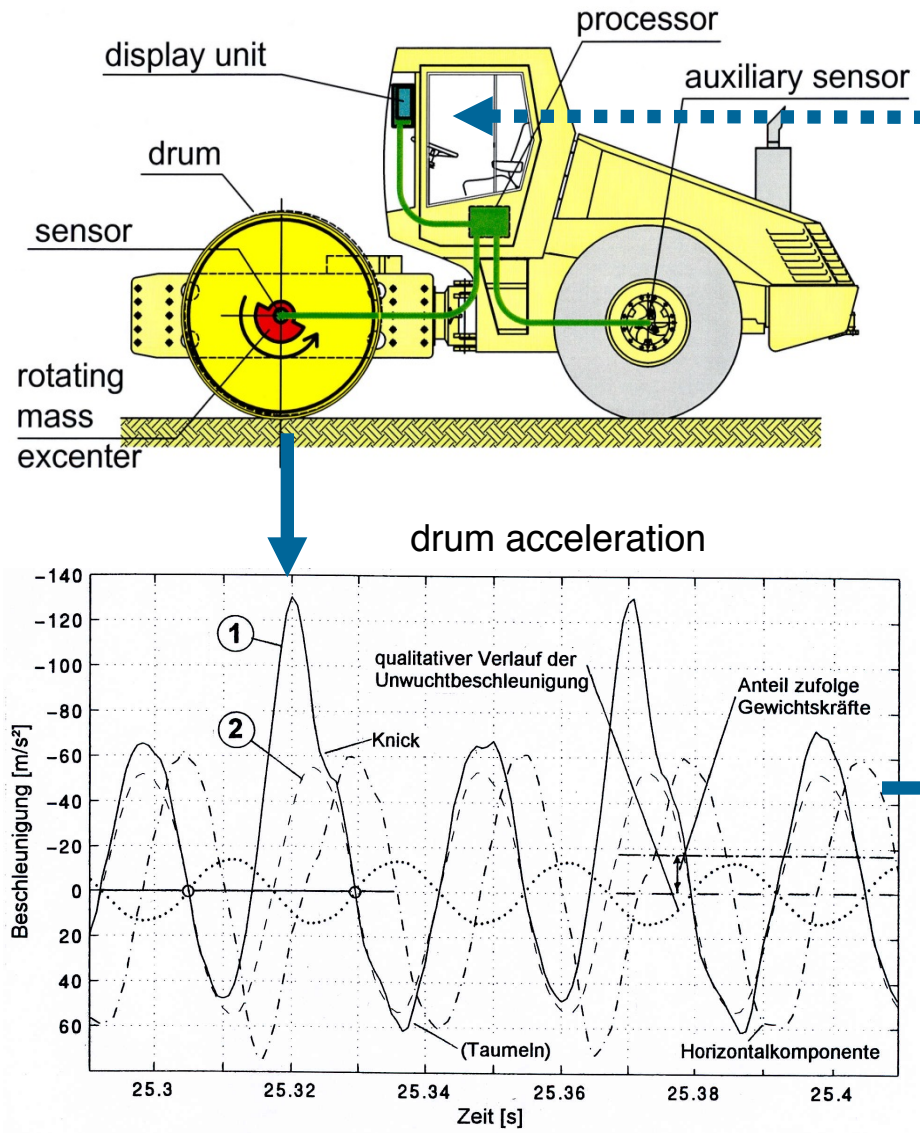
- eccentric mass in the drum axis
- circular translational vibration of the drum
- mainly vertical loading
- better compaction depth

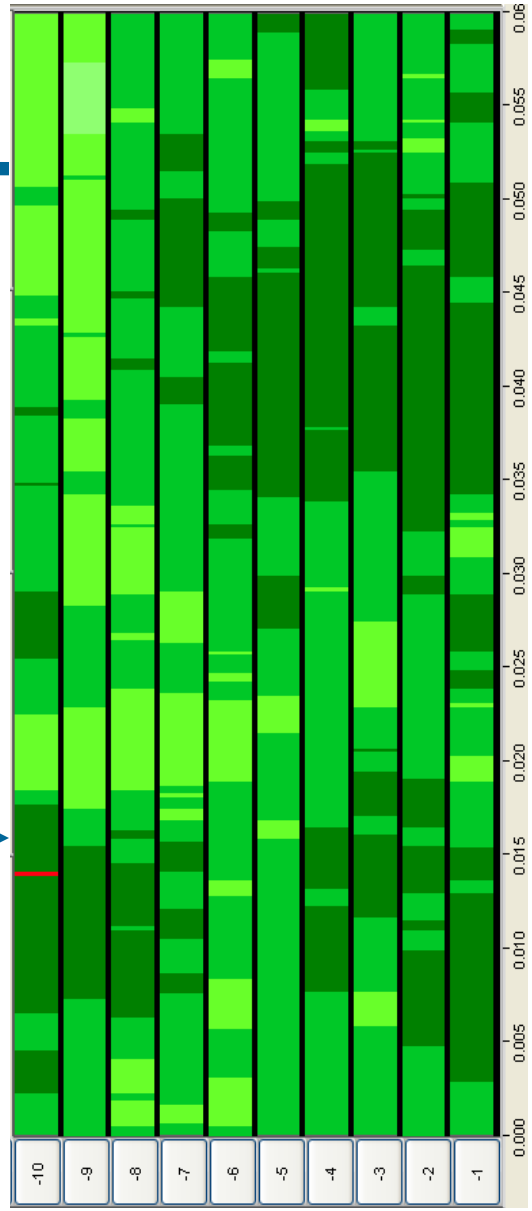


Modes of operation:

Continuous Contact, Partial Uplift, Double Jump, Rocking Motion, Chaotic Motion

drum motion	interaction drum-soil	mode of operation	soil contact force	application of CCC	soil stiffness	roller speed	drum amplitude
periodic	cont. contact	Continuous Contact		yes	low	fast	small
periodic	periodic loss of contact	Partial Uplift		yes	↓	↓	↓
periodic	periodic loss of contact	Double Jump		yes	↓	↓	↓
periodic	periodic loss of contact	Rocking Motion		no	↓	↓	↓
chaotic	non-periodic loss of contact	Chaotic Motion		no	high	slow	large


processor
display unit
auxiliary sensor
drum
sensor
rotating
mass
excenter
drum acceleration
Beschleunigung [m/s²]
Zeit [s]
qualitativer Verlauf der
Unwuchtbeschleunigung
Anteil zufolge
Gewichtskräfte
Knick
(Taumeln)
Horizontalkomponente
1
2



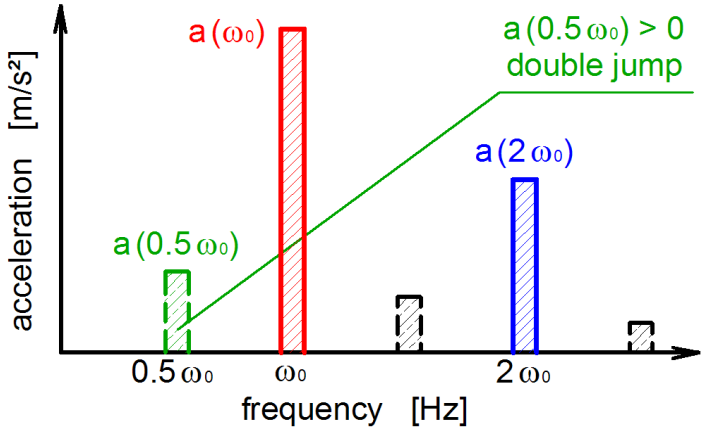
CCC Values

Compactometer

CMV

is based on the evaluation of the acceleration in the *frequency domain*

$$CMV = Faktor_1 \frac{a(2\omega_0)}{a(\omega_0)} \qquad RMV = Faktor_2 \frac{a(0.5\omega_0)}{a(\omega_0)}$$

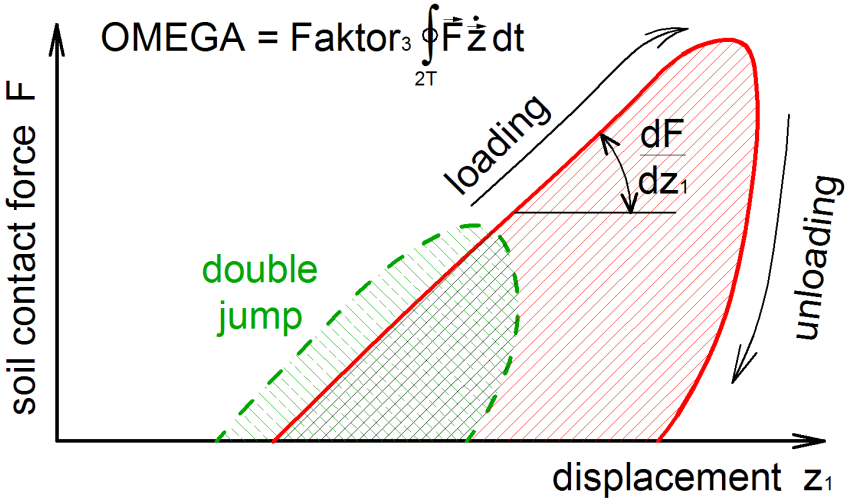


Terrameter

OMEGA

is based on the evaluation of the energy transmitted to the soil in the *time domain*

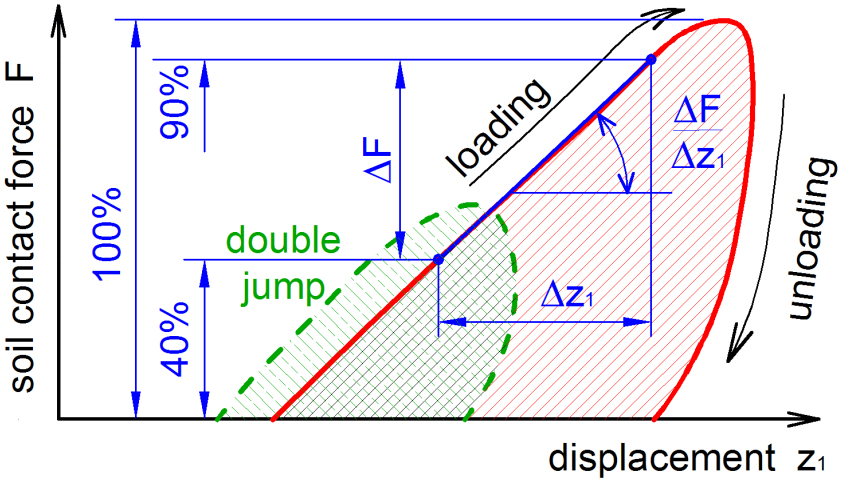
$$OMEGA = Faktor_3 \oint_{2T} \vec{F}\dot{\vec{z}}\,dt$$



Terrameter

E_{VIB}

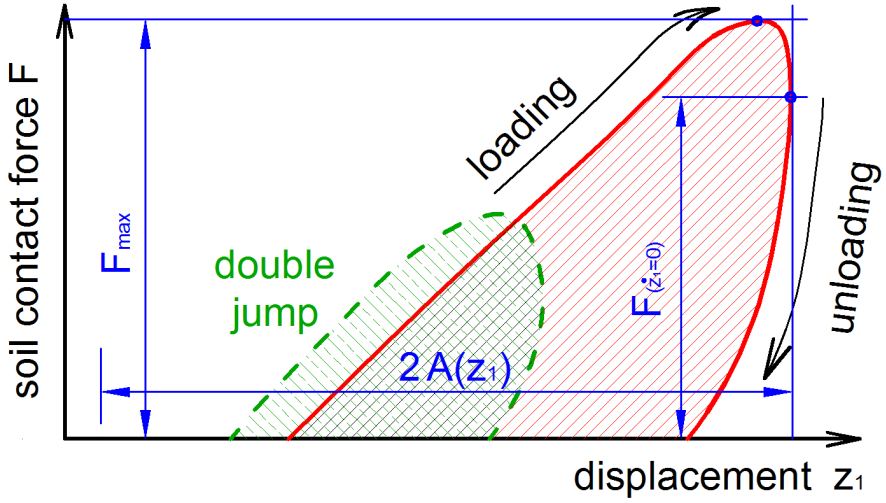
⇨ inclination of the soil contact force displacement relationship during loading; *time domain*



ACE

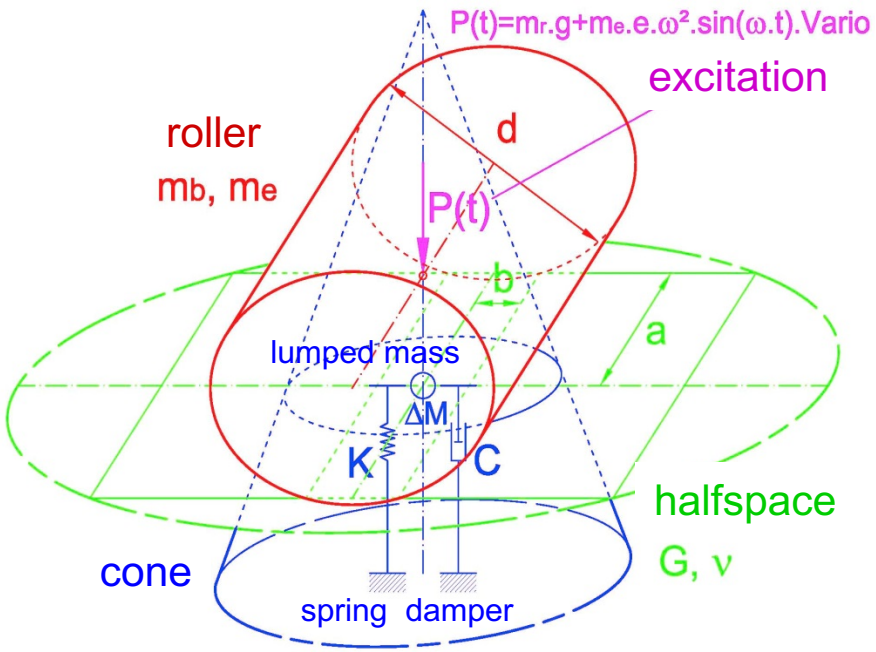
k_B

⇨ derived from the soil contact force displacement relationship at maximum drum deflection; *time domain*

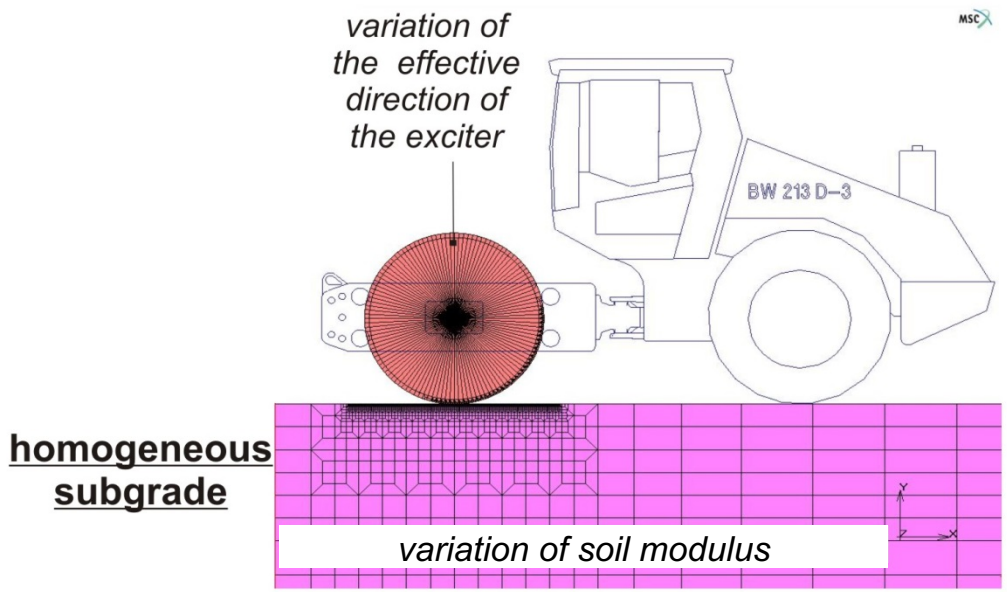


Modelling of the dynamic soil roller interaction system

Semi-analytical modelling



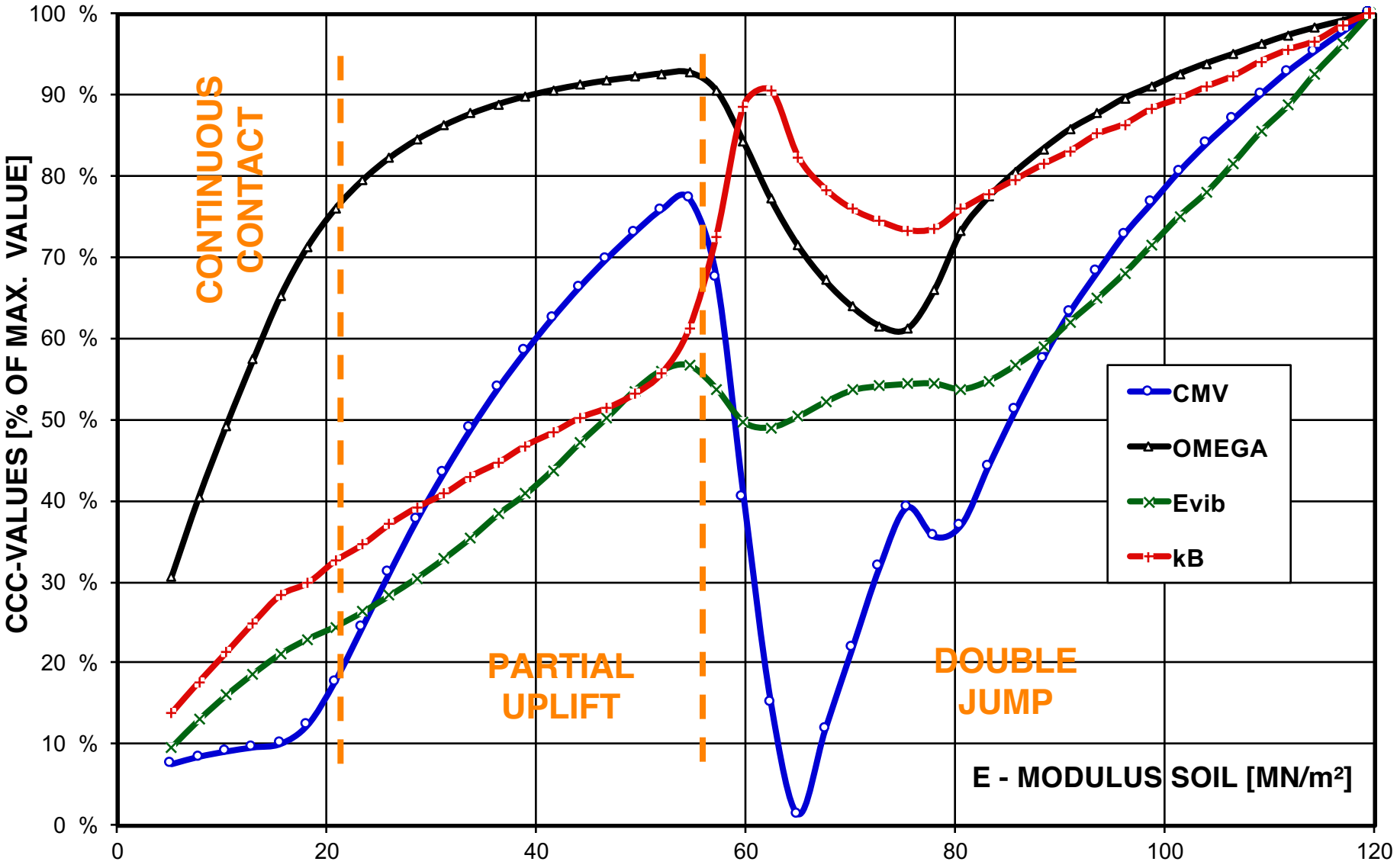
Finite element modelling

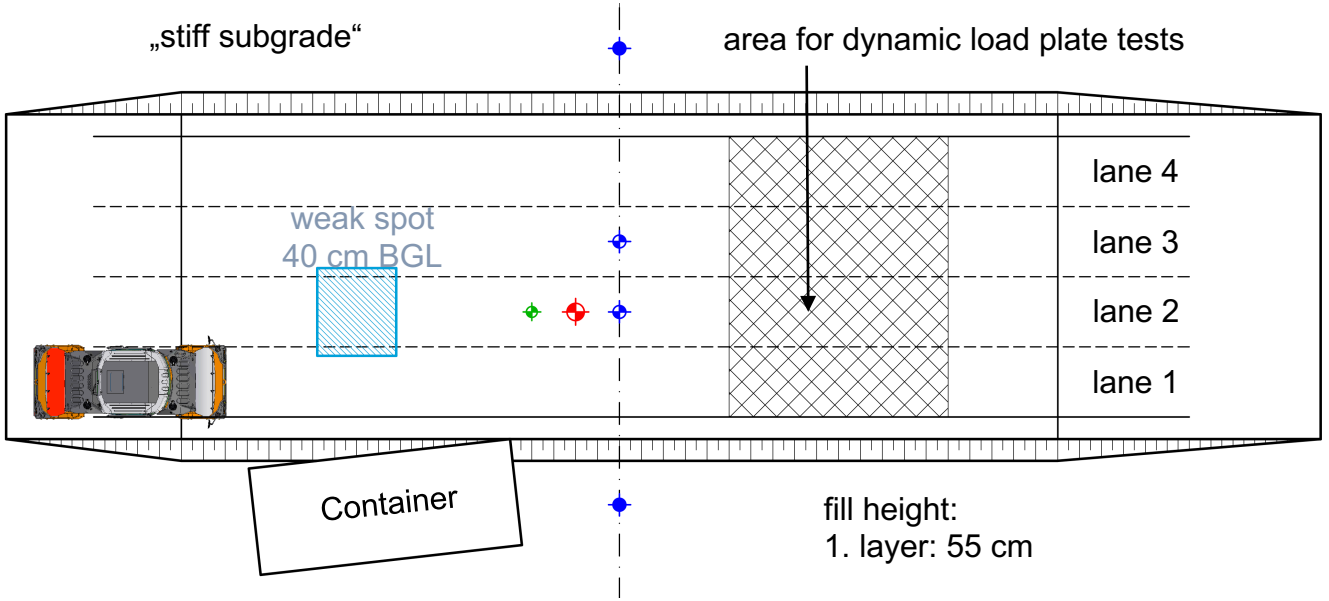


Roller drum: rigid body with directed excitation unit
Ground: approximation of linear elastic halfspace
→ cone model (SDOF) (*Wolf*, 1994)

→ linear elastic elements

Contact problem: relevant non-linearity in the interaction system


CCC-VALUES [% OF MAX. VALUE]
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
0
20
40
60
80
100
120
CONTINUOUS CONTACT
PARTIAL UPLIFT
DOUBLE JUMP
E - MODULUS SOIL [MN/m²]
CMV
OMEGA
Evib
kB



fill height:
1. layer: 55 cm

fill material:
sandy gravel

- Tri-axial accelerometer 55 cm BGL
- Tri-axial accelerometer on the surface
- Deformation measurement device
- Dynamic soil pressure 55 cm BGL
- Reference point of geodetic levelling

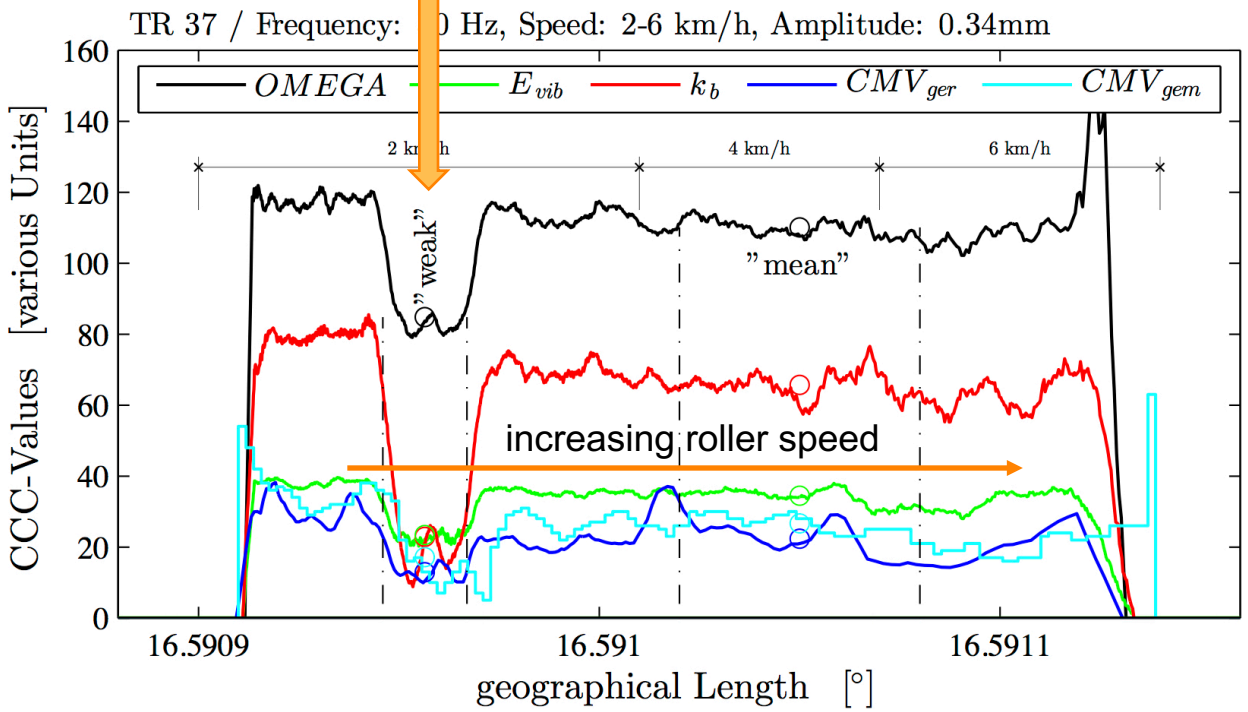
Compaction device:
HAMM HD+ 90 VO tandem roller (ca. 9.8 t)

Vibration (ca. 1.9 t drum mass):
Small amplitude: 0.34 mm at 50 Hz
Large amplitude: 0.62 mm at 40 Hz

Oscillation (ca. 1.9 t drum mass):
Tangential amplitude: 1.44 mm at 39 Hz

Calculation of the CCC values based on acceleration measurements:

Lane 2, Vibration, *f* = 50 Hz, *v* = 2-6 km/h

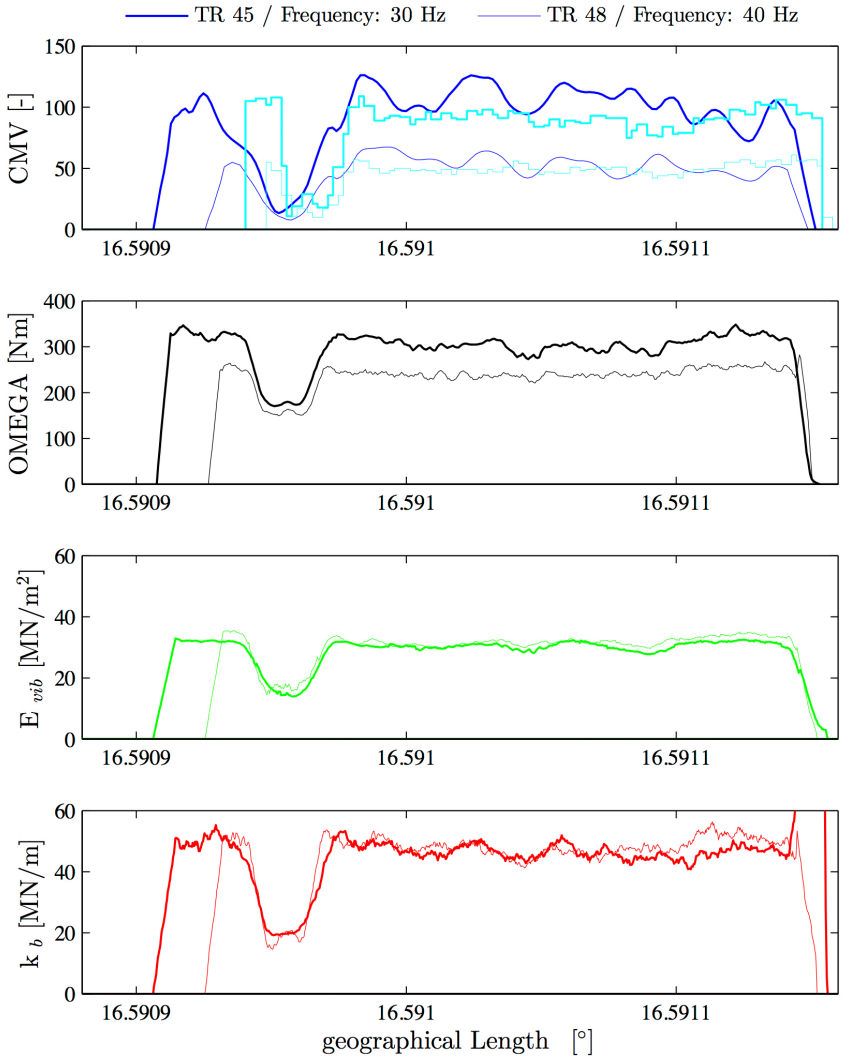


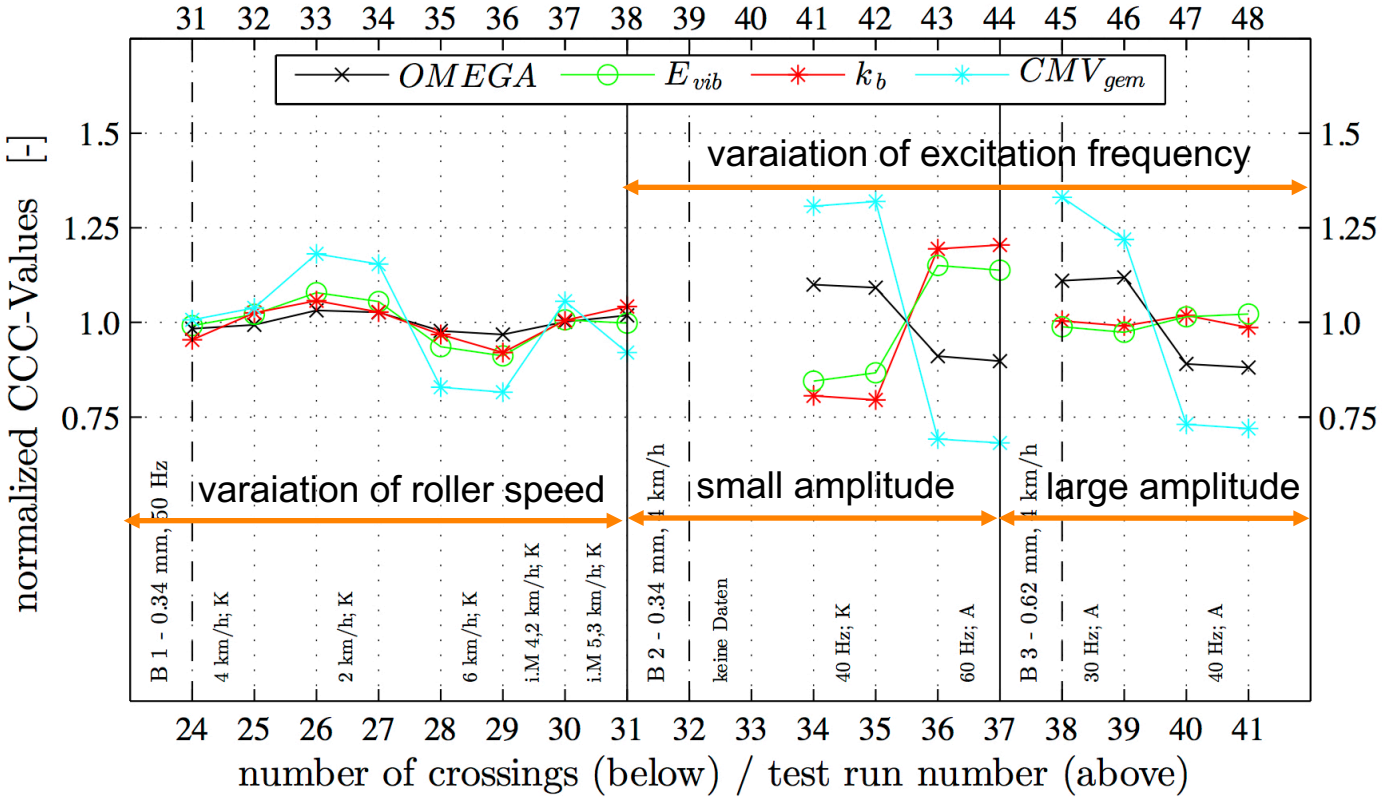
Installation of the artificial weak spot

Dynamic load plate tests after each roller pass

Comparison of two test runs:

f = 40 Hz (thin line) and f = 30 Hz (bold line)





Main influence on CCC values:

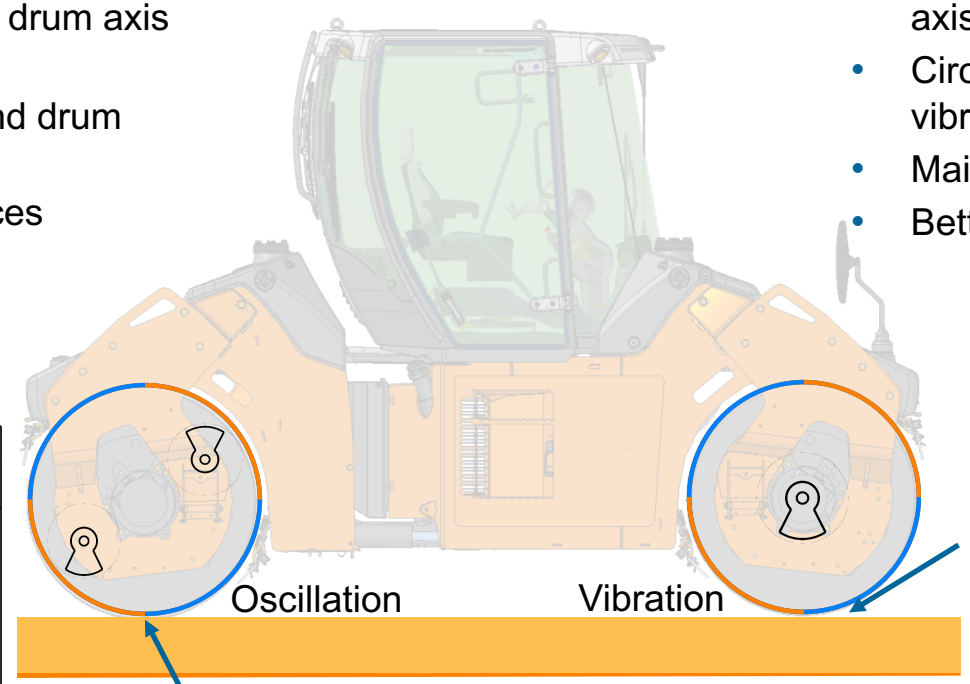
- Modes of operation
- Roller speed
- Excitation frequency
- Excitation amplitude

Oscillating rollers:

- Two eccentric masses – eccentric, but point symmetric to the drum axis
- Same sence of rotation
  ⇒ sinusoidal torque around drum axis
- Mainly dynamic shear forces
- Low ambient vibrations
- Until recently:
  no CCC system!

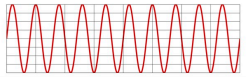
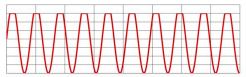
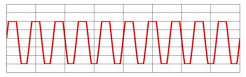
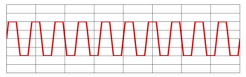
Vibrating rollers:

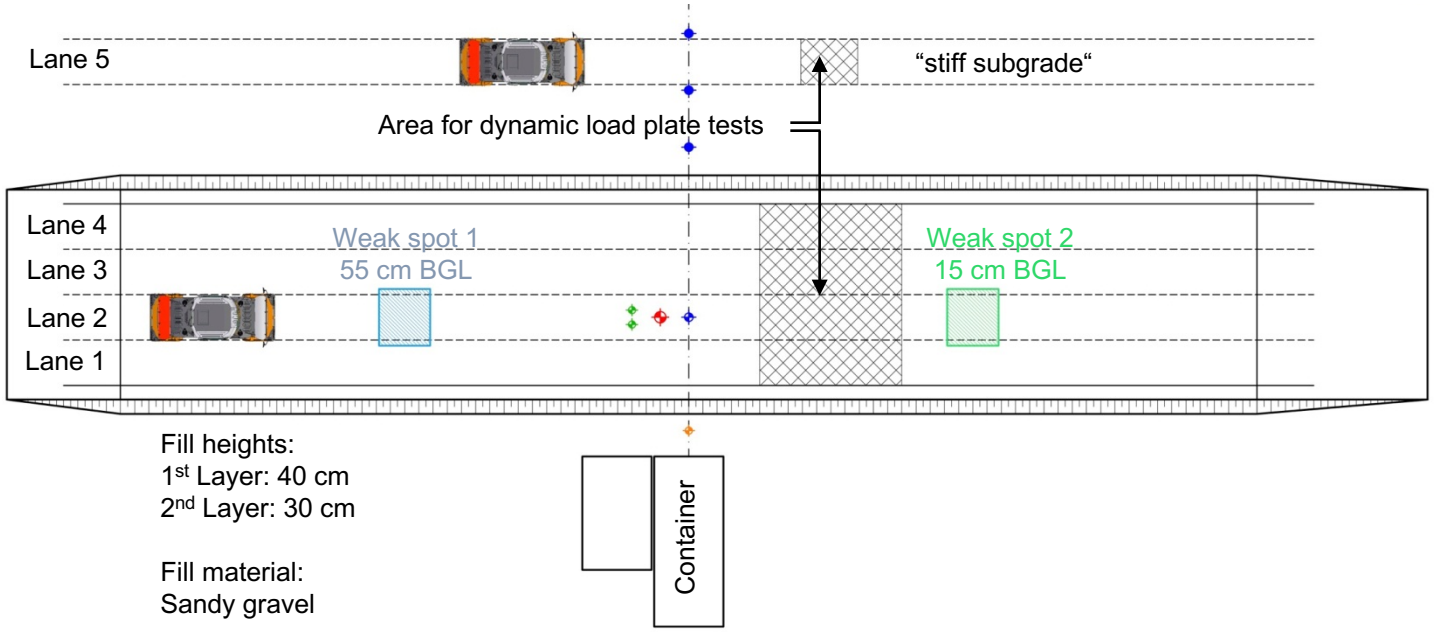
- Eccentric mass in the drum axis
- Circular translational vibration of the drum
- Mainly vertical loading
- Better compaction depth



Modes of operation:
Continuous Contact, Partial Uplift, Double Jump, Rocking Motion, Chaos

Modes of operation:
Stick, One-sided Slip, Asymmetric Slip, Symmetric Slip

interaction drum-soil	mode of operation	horizontal acceleration in the bearing	app. of CCC	roller speed	soil stiffness	excitation amplitude	excitation frequency
continuous contact	Stick		yes	slow	low (Stick)	small (Stick)	low (Stick)
periodic loss of contact	One-sided Slip		yes	↓	↓	↓	↓
	Asymmetric Slip		yes		high (Slip)	large (Slip)	high (Slip)
	Symmetric Slip		yes	fast			



- Tri-axial accelerometer 70 cm BGL
- Tri-axial accelerometer on the surface
- Deformation measurement device
- Dynamic earth pressure cell 70 cm BGL
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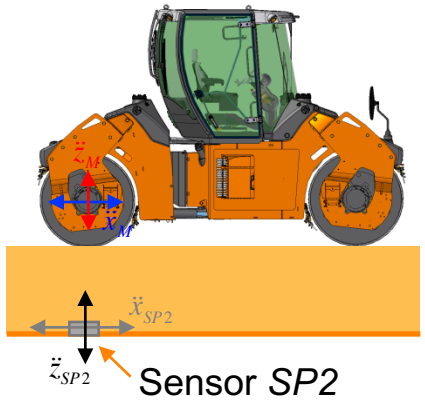
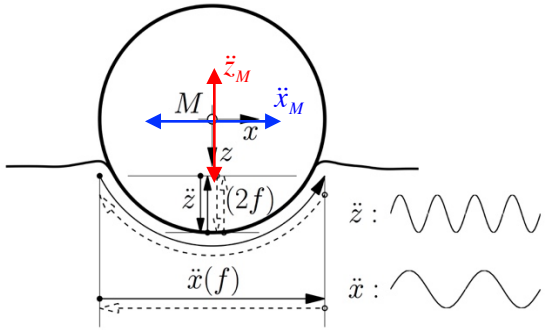
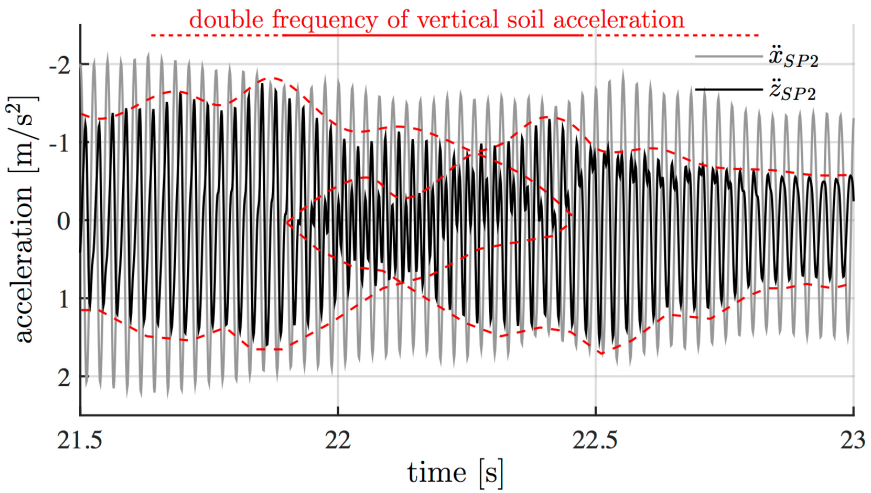
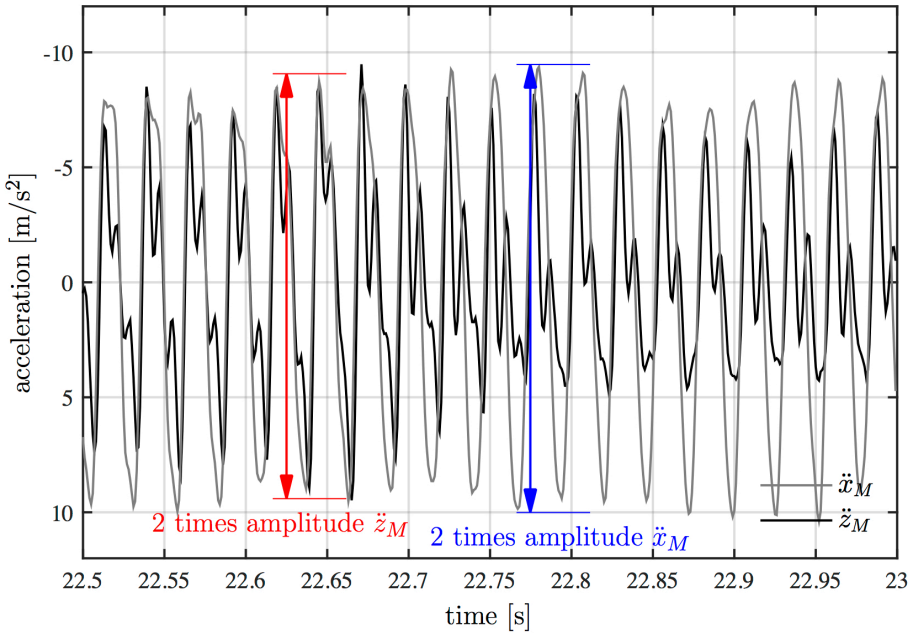
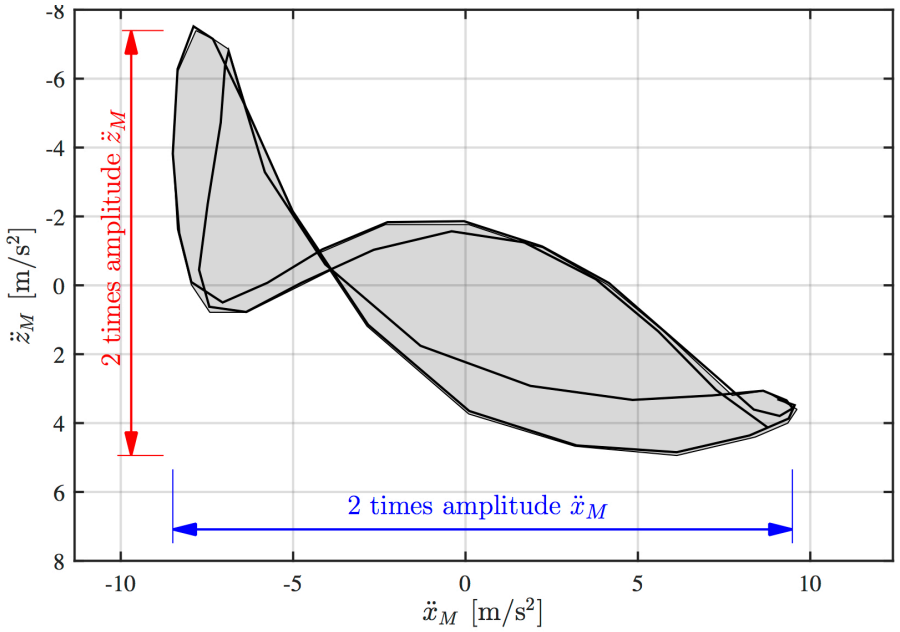






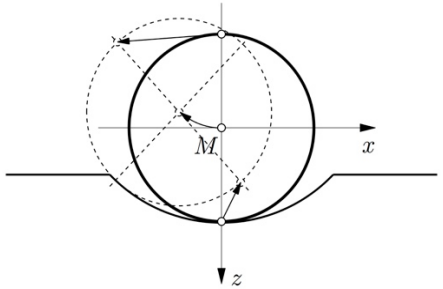
Accelerations in the bearing of the drum (point *M*):





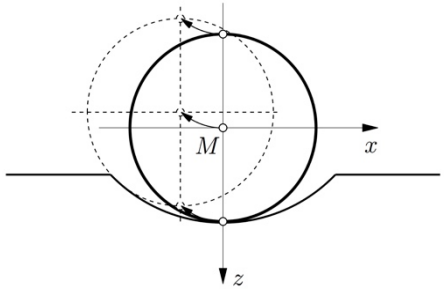
Motion behaviour of point *M*:

Rotary motion:



Mode of operation **Stick**

Translatory motion:



Mode of operation **Slip**

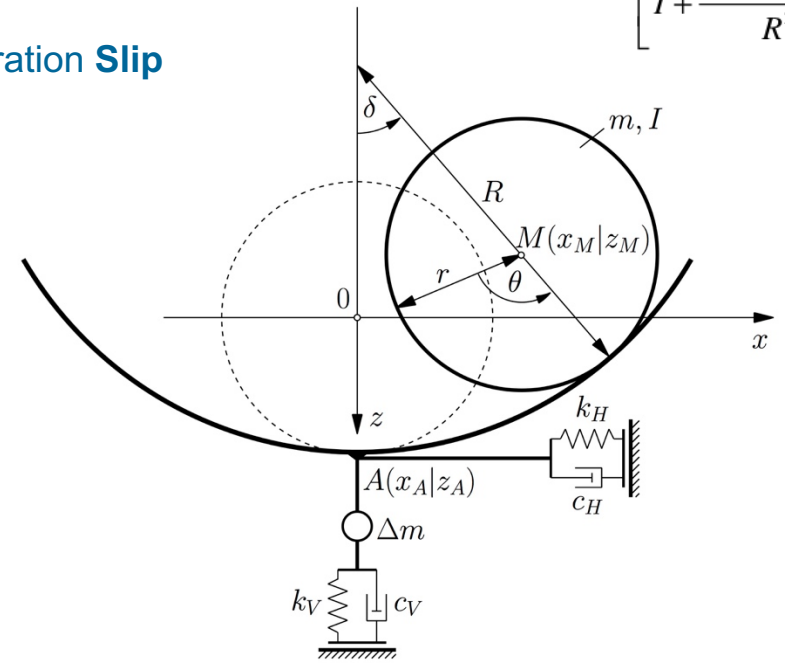
Mode independence!

Formulation of the equations of motion:

$$m\ddot{x}_A + \frac{mr(R-r)}{R}\ddot{\theta} - \frac{mr^2(R-r)}{R^2}\dot{\theta}^2\theta + k_H x_A + c_H \dot{x}_A = 0$$

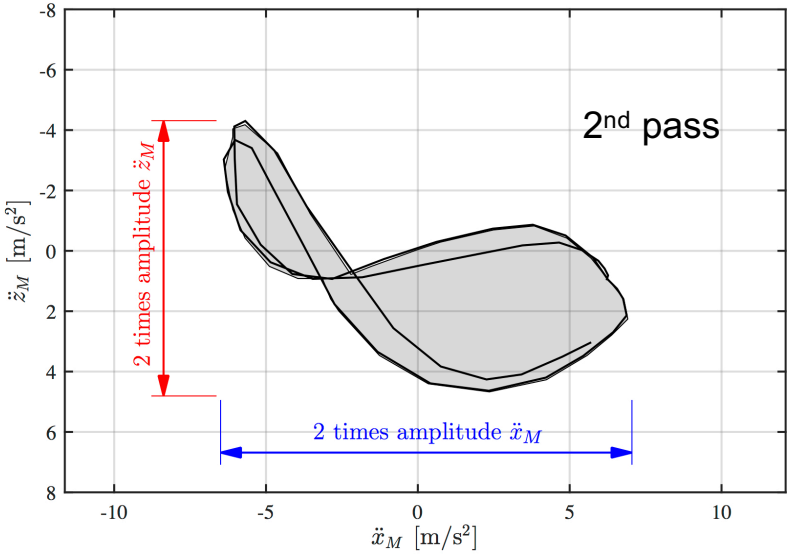
$$(m+\Delta m)\ddot{z}_A - \frac{mr(R-r)}{R}\frac{r}{R}\ddot{\theta}\theta - \frac{mr^2(R-r)}{R^2}\dot{\theta}^2 + k_V z_A - mg + c_V \dot{z}_A = F_z$$

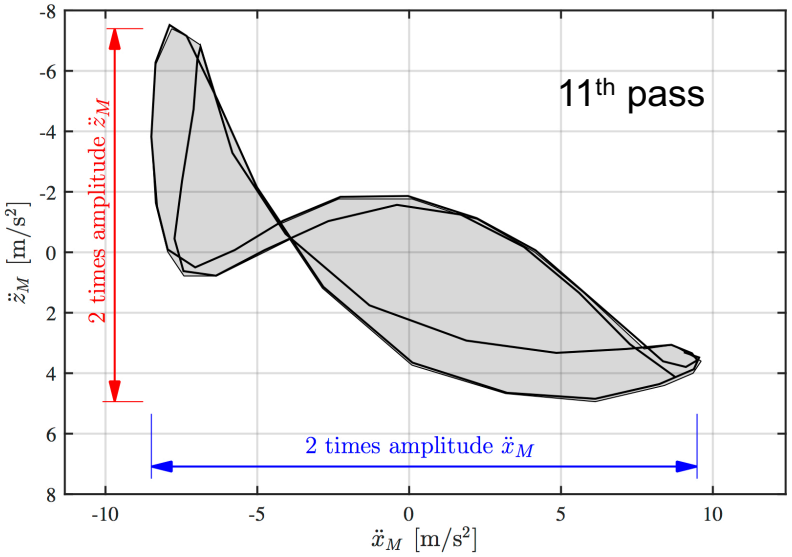
$$\left[I + \frac{mr^2(R-r)^2}{R^2}\right]\ddot{\theta} + \frac{mr(R-r)}{R}\ddot{x}_A - \frac{mr^2(R-r)}{R^2}\ddot{z}_A\theta + mg(R-r)\frac{r^2}{R^2}\theta = M_0 \sin(\xi t)$$



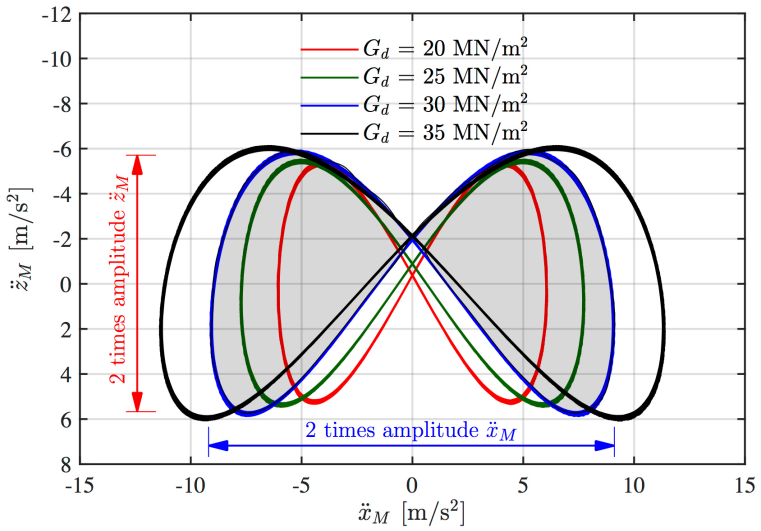
Mechanical model

- Results of the experimental measurements:





- Results of the model analysis:

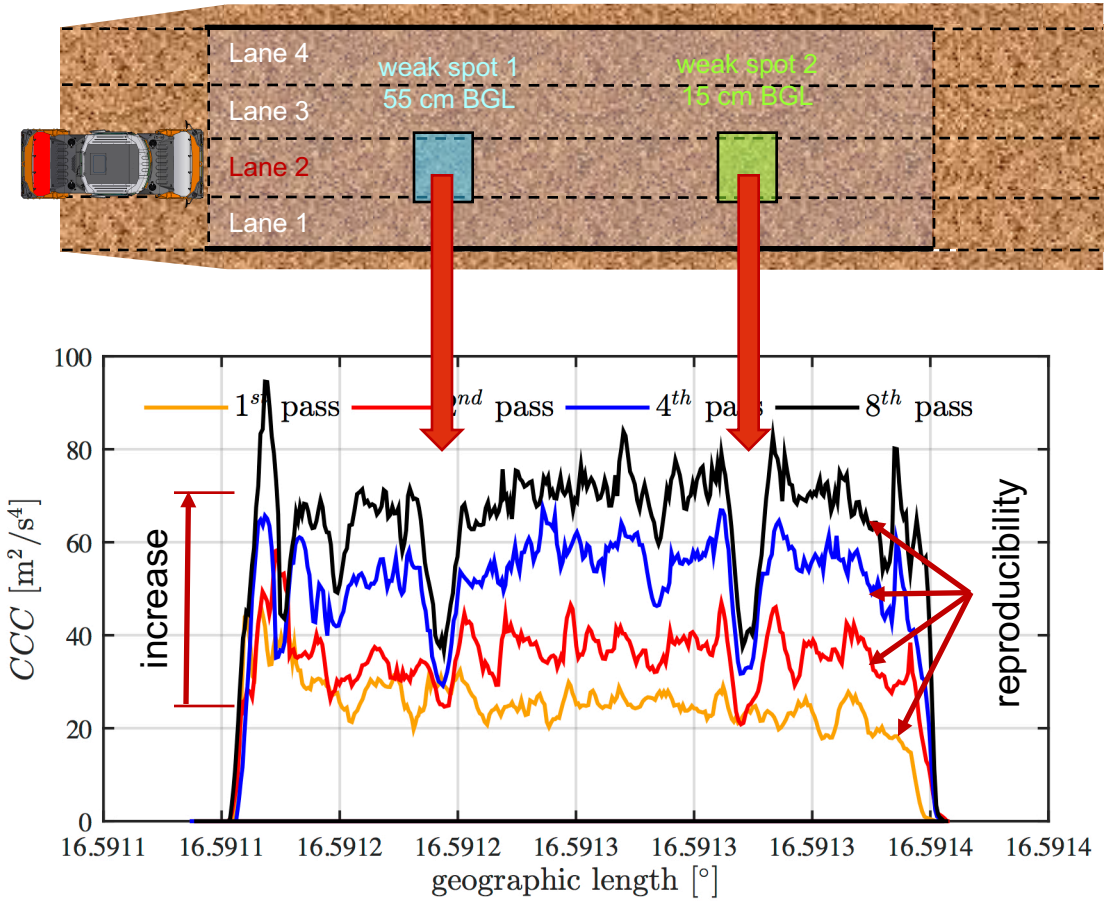


- Expansion of the eight shape
  - with increasing number of passes
  - with increasing soil stiffness
- Distortion of the shape caused by travelling motion
- Characterisation of the shape = possible CCC

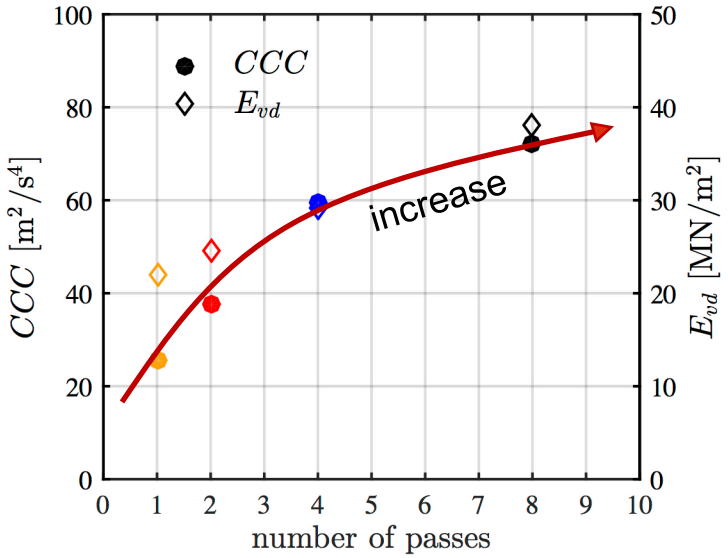
- Definition: area of the shape = CCC value for oscillating rollers

Application of the CCC algorithm on acceleration measurements:

2nd layer, lane 2, Oscillation, f = 39 Hz, v = 4 km/h



Comparison to dynamic load plate tests:



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