Intelligent Compaction

ACE plus

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…GPS-based Compaction Control

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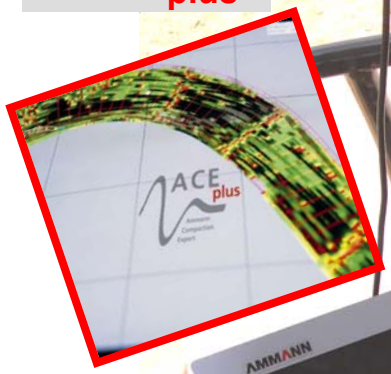
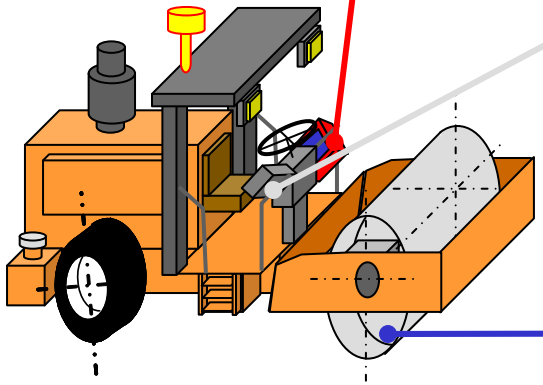
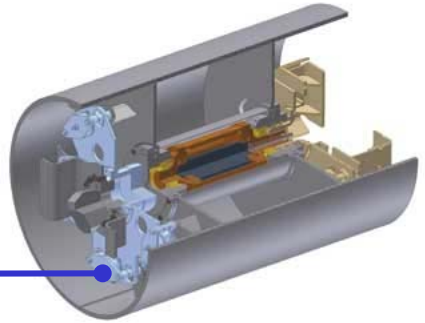


ACE$_{plus}$-Display

ACE$_{plus}$ Drum





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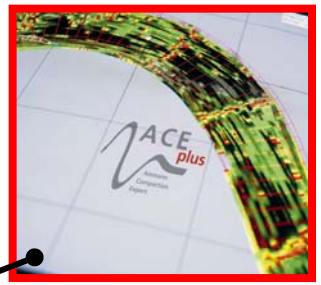
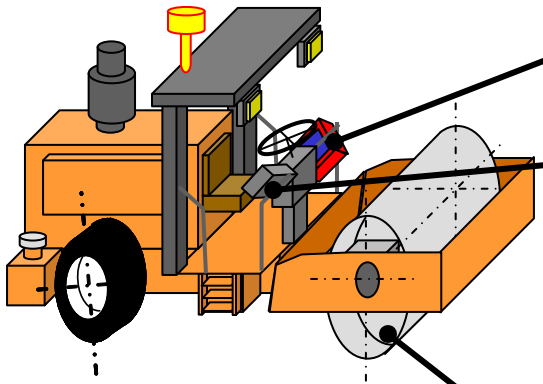
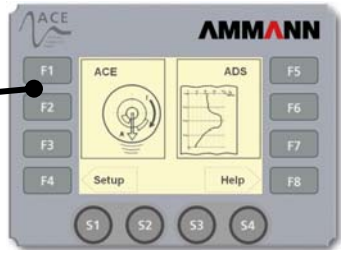
Single Drum Roller SV 212 ACE$_{plus}$

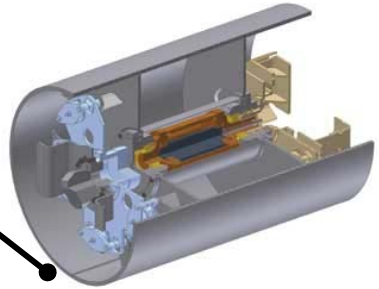


ACE$_{plus}$
- Stiffness k_B [MN/m]
- Number of Passes
- Process-Improvement





ACE-Display
- Material Preselection
- Compaction Values



Drum
- Amplitude changes stepless
- variable Frequency

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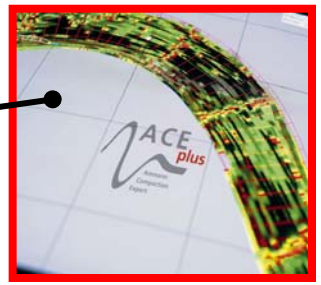
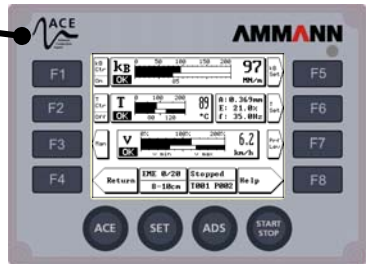
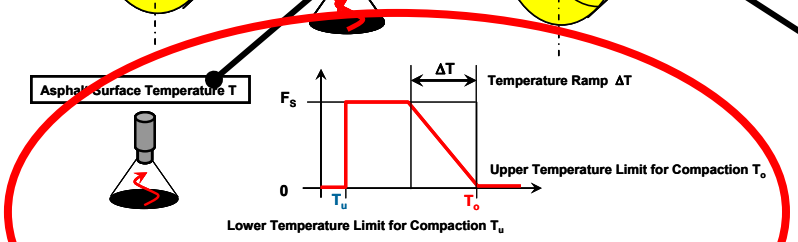
Tandem Roller AV 95-II ACE$_{plus}$: additional Temp.-Measurement



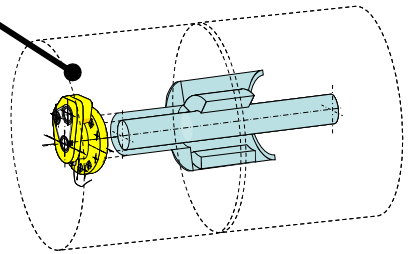
ACE$_{plus}$
- stiffness, Temperature
- number of passes
- process-improvement



ACE-Display
- material preselection
- compaction values
- Asphalt Temperature



Asphalt Surface Temperature
- Infrared measurement principle



Drum (splitted)
- amplitude changes stepless
- variable frequency

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ACE$_{plus}$: GPS-based Asphalt Compaction Control

Intelligent Compaction on Asphalt Job Sites

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IC Equipment - Basic Elements

1. Automatic Feedback Control System
   for Roller Parameters (Amplitude & Frequency)

2. In-situ Measurement of Material Stiffness

3. GPS-based Compaction Control, QA/QC

References (I)

[1] Asphalt Institute — ***Soils Manual; Chapter VIII: Bearing Plate Determination*** *(Plate Bearing Test) pp. 93-110,* Asphalt Institute, Manual Series No. 10 (MS-10), 5th Edition, Lexington KY

[2] Richard D. Barksdale — ***The Aggregate Handbook*** 4th Printing, National Stone Association, Washington D. C., 2001

[3] Asphalte Institute — ***The Asphalt Handbook; Chapter 7: Compacting Hot-Mix Asphalt****, pp. 283-307* Asphalt Institute, Manual Series No. 4 (MS-4), Edition 1989

[4] Anderegg & Kaufmann — ***Intelligent Compaction with Vibratory Rollers*** *– Feedback Control Systems in Automatic Compaction and Compaction Control;* Journal of the Transportation Research Board (TRB), Soil Mechanics 2004 No. 1868, pp. 124-134, Washington D. C. 2004

[5] Anderegg, von Felten & Kaufmann — ***Compaction Monitoring using Intelligent Soil Compactors****;* Presentation and Proceedings ASCE GeoCongress 2006, Atlanta February 2006

[6] Mike Mooney, R. Rinehart — ***The Influence of Heterogeneity on Vibratory Roller Compactor Response*** Presentation and Proceedings ASCE, GeoCongress 2006, Atlanta February 2006

[7] Mike Mooney, R. Rinehart — ***Field Monitoring of Roller Vibration during Compaction of Subgrade Soil*** Journal of Geotechnical and Geoenvironmental Engineering, ASCE 2007

[8] David White — ***Field Validation of Intelligent Compaction Monitoring Technology for Unbound Materials and hot Mix Asphalts***; Interim Project Report, TH14 Janesville MN, 10/28 – 7/11 2005 CTRE, Iowa State University, Ames IA March 2006

[9] C. K. Su — ***The new Age of Rolling – The North Carolina Experience***; IC Strategic Meeting, Aubrun AL, 2004

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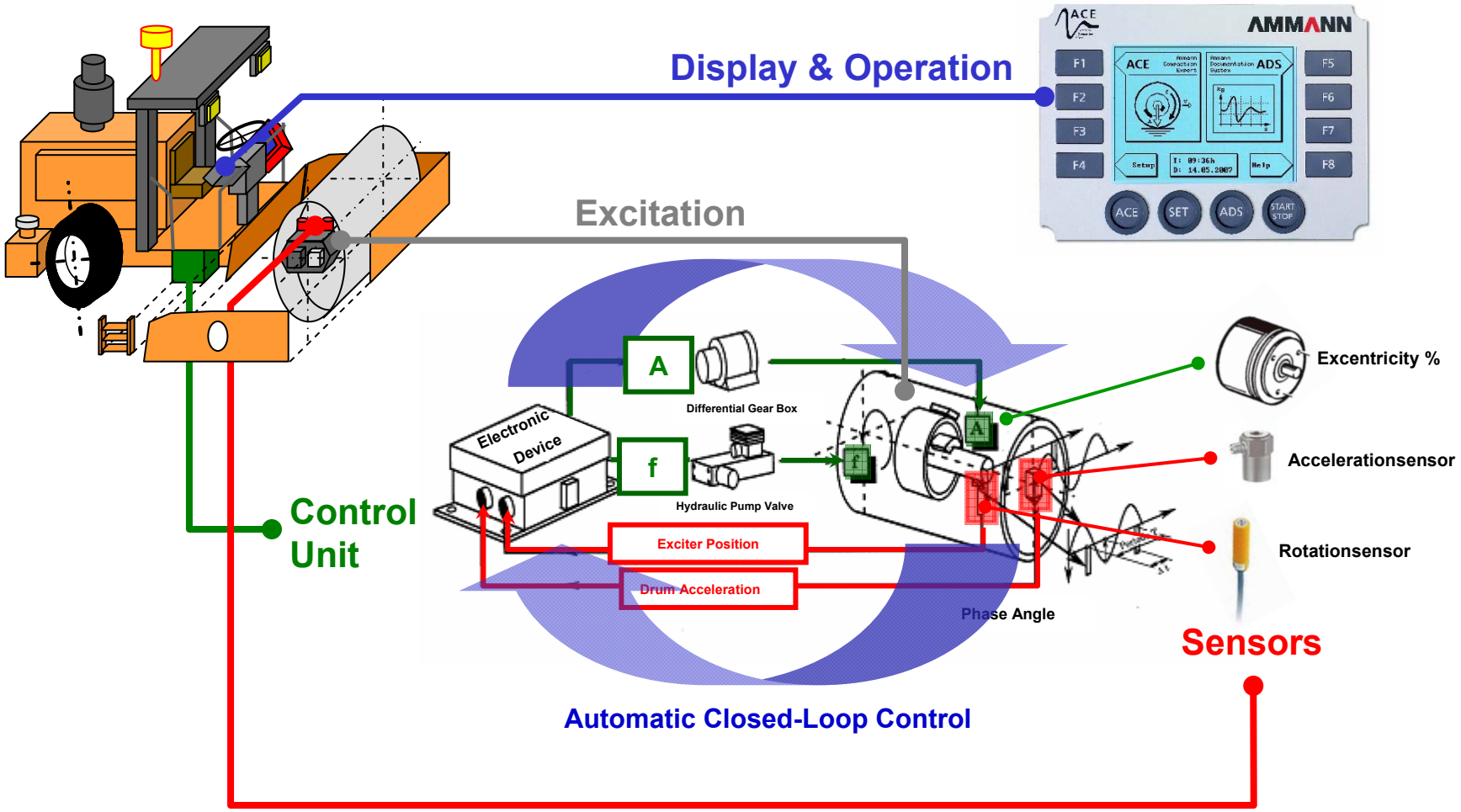
[10] Preisig, Noesberger Dr. Caprez, Prof. Amann R. Anderegg — ***Continuous Compaction Control based on Geotechnical Parameters*** Forschungsauftrag VSS 2000/353; Federal Institute of Technology ETH, Zurich 2006

[11] Preisig, Dr. Caprez & Prof. Amann — ***Validation of Continuous Compaction Control (CCC) Methods*** Paper and Presentation: 9/23/2003; Workshop on Soil Compaction Technical University of Hamburg-Harburg, Germany

[12] Kuno Kaufmann — ***Higher Compaction Performance using two Excitation Frequencies*** Master Thesis (MSc.), in German with an English Abstract Bern University of Applied Sciences, Engineering and Information Technology Burgdorf (Switzerland) 2006

[13] A. Teferra, E. Schultze — ***Formulae, Charts and Tables – Soil Mechanics and Foundation Engineerings*** Stresses in Soils A. A. Balkema, Rotterdam & Brookfield 1998

ACE$_{plus}$: Control Loop & Sensors [5]



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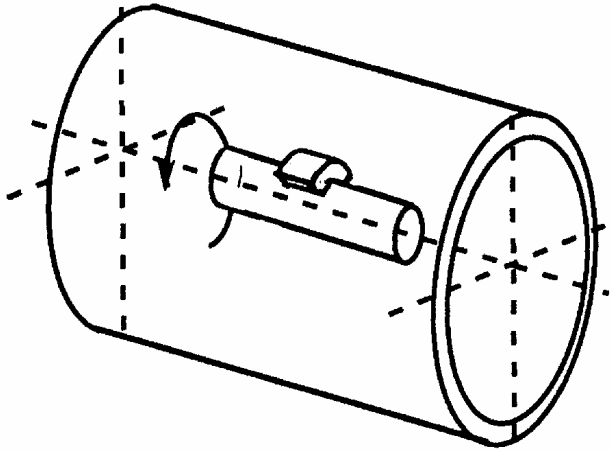
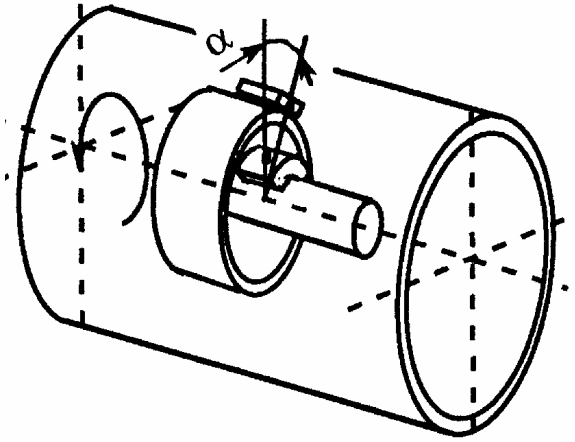
1-Amplitude-Machine

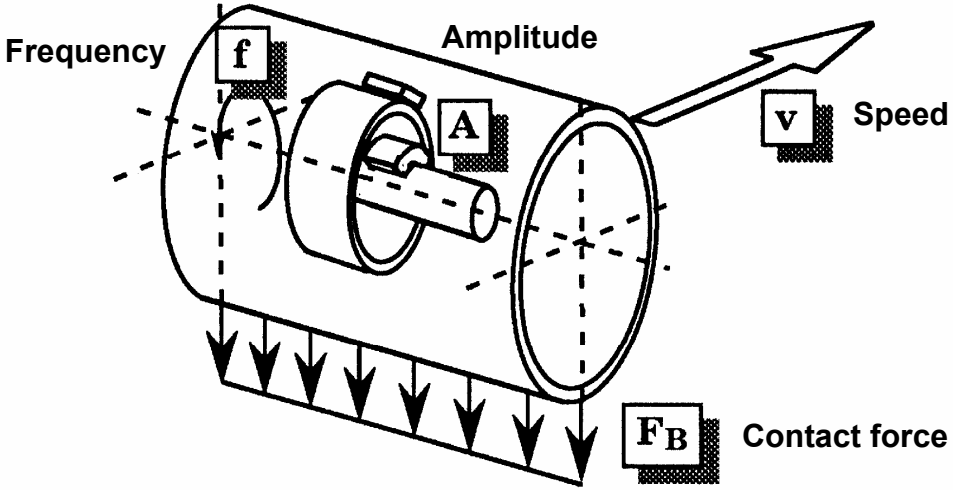


Continuously changement of the amplitude



ACE Ammann Compaction Expert

Automatically Controlled Roller Parameter



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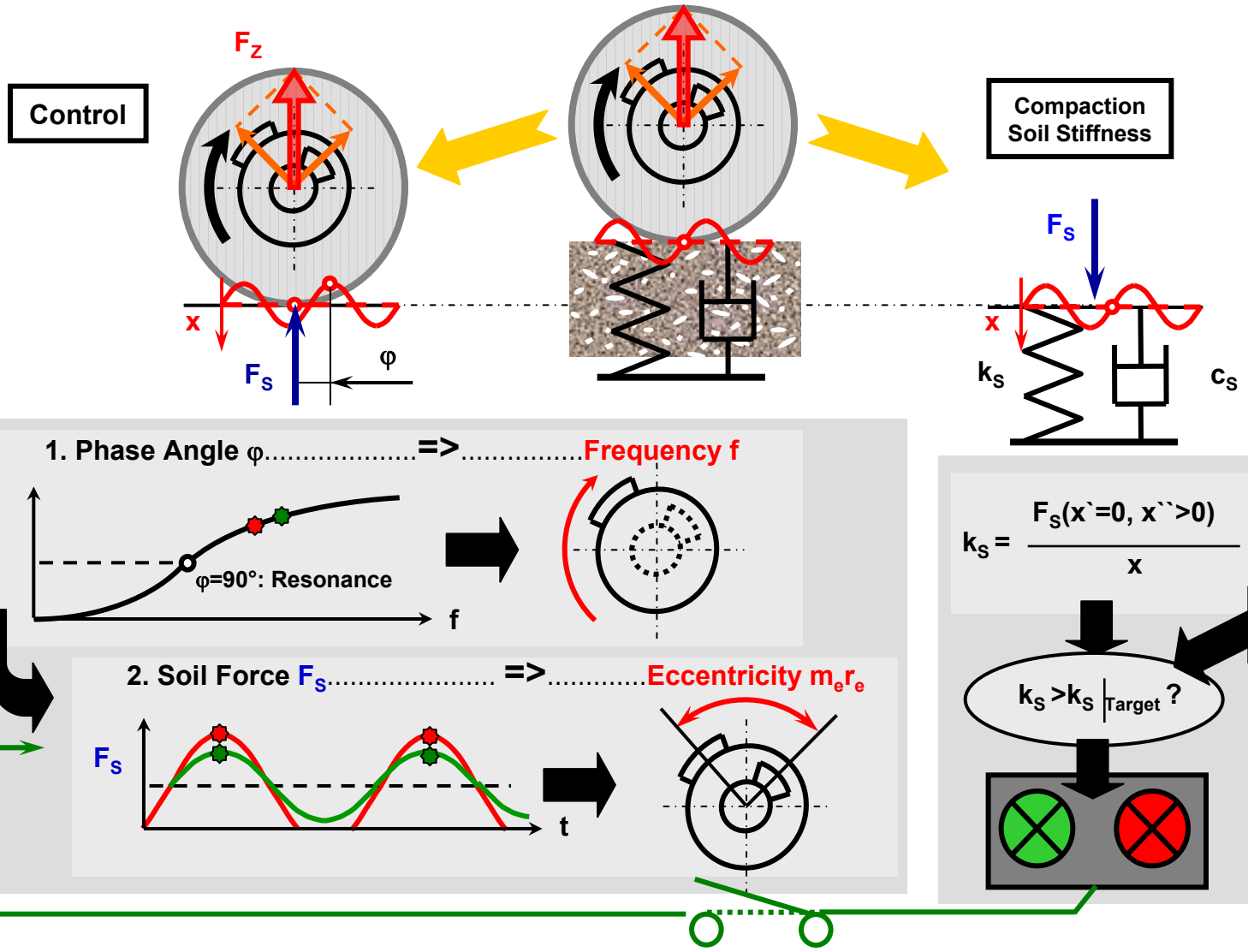
ACE$_{plus}$: Control of Machine Parameters [5]



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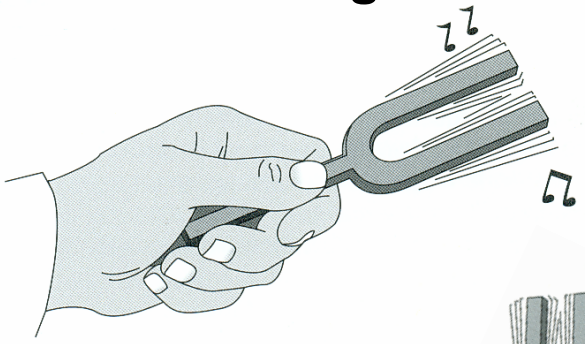
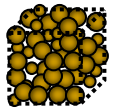
Searching the Resonance Frequency [4]



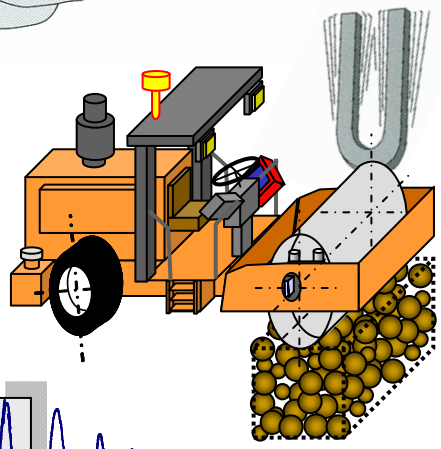
Natural Frequency: the Frequency at which an Object vibrates by itself
This is the Point of maximum transmitted Force

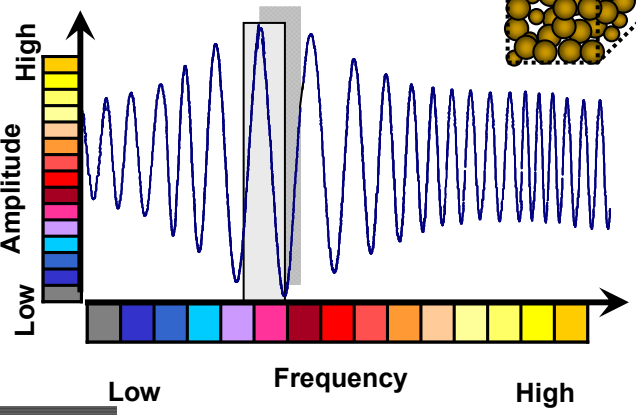
Weak Material



Loam

- low Frequency
- high Amplitude

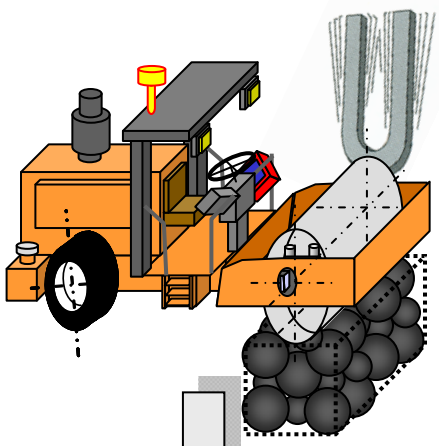


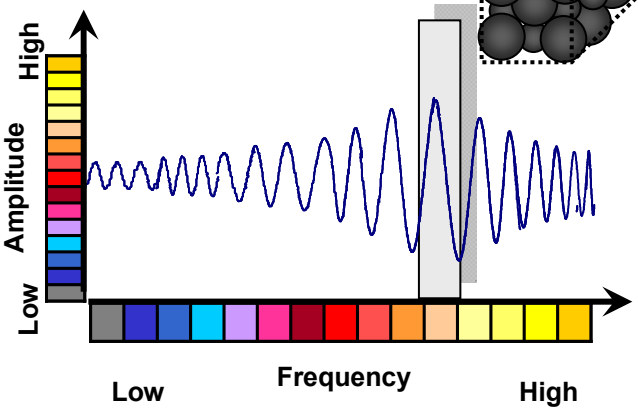


Hard Material

Gravel

- high Frequency
- low Amplitude





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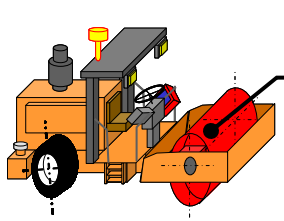
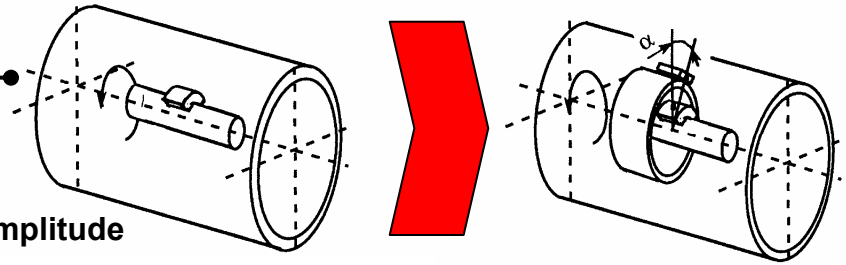
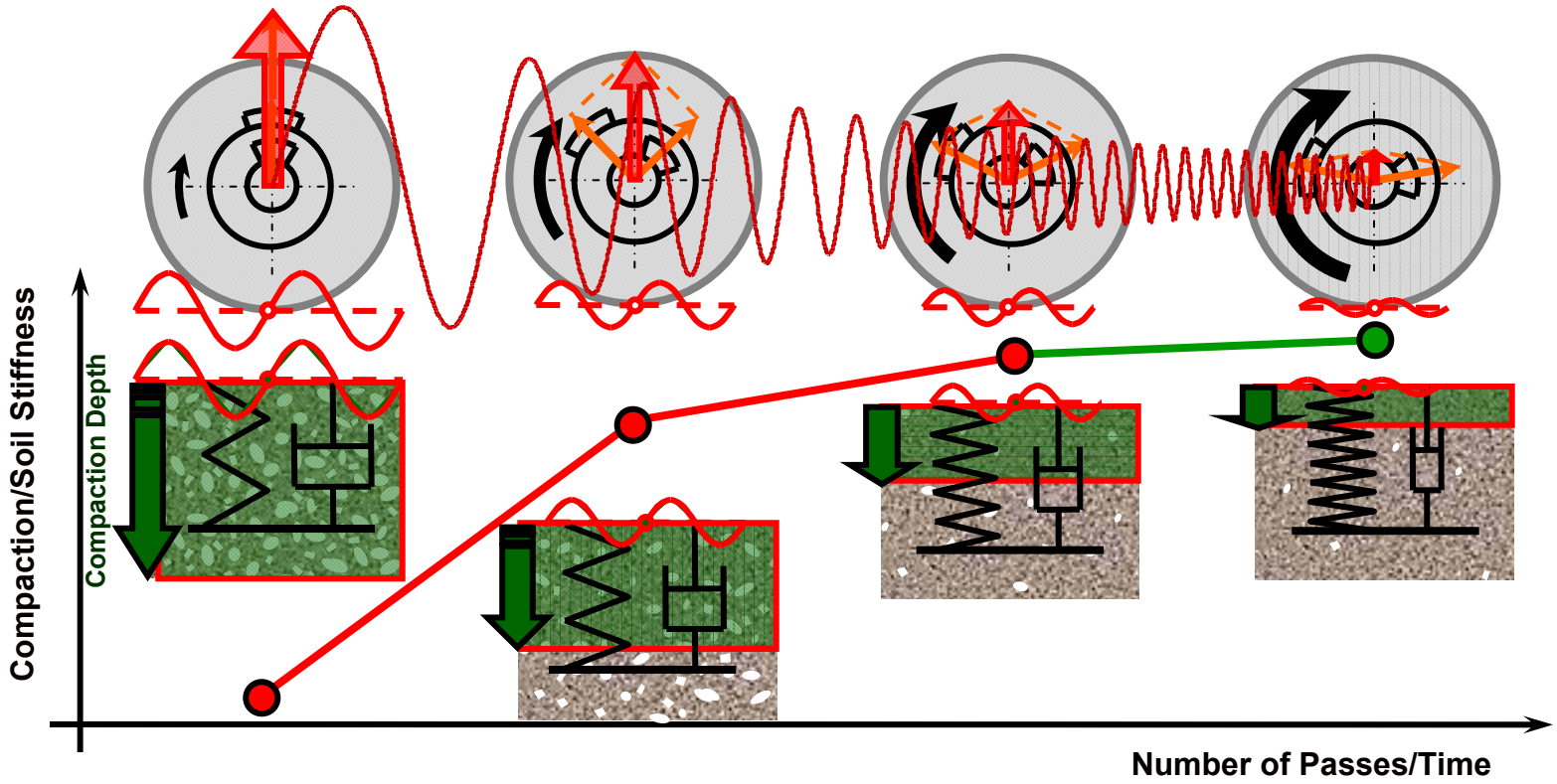


Drum



1-Amplitude

Continuously changement of the amplitude



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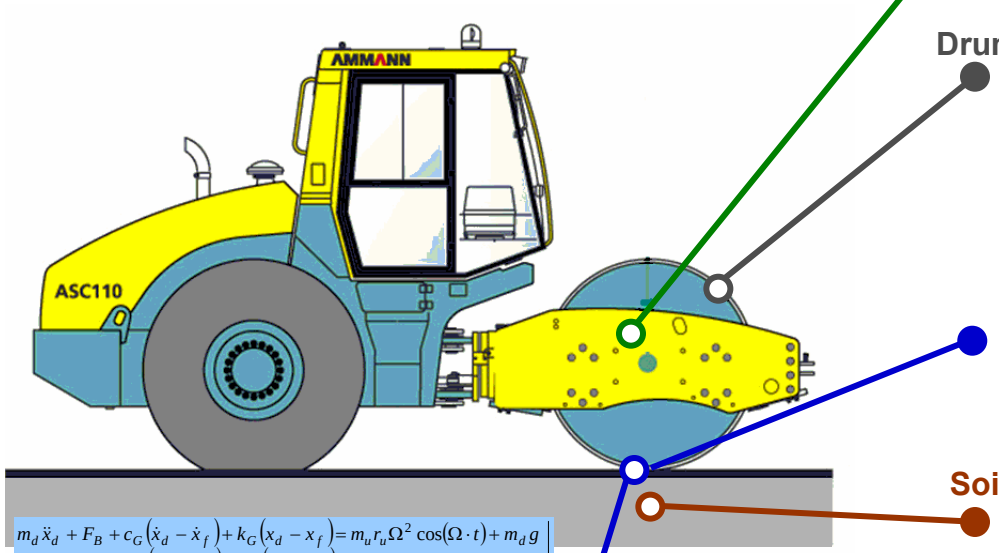
Analytical Model [4], [5], [7]



Frame

Drum

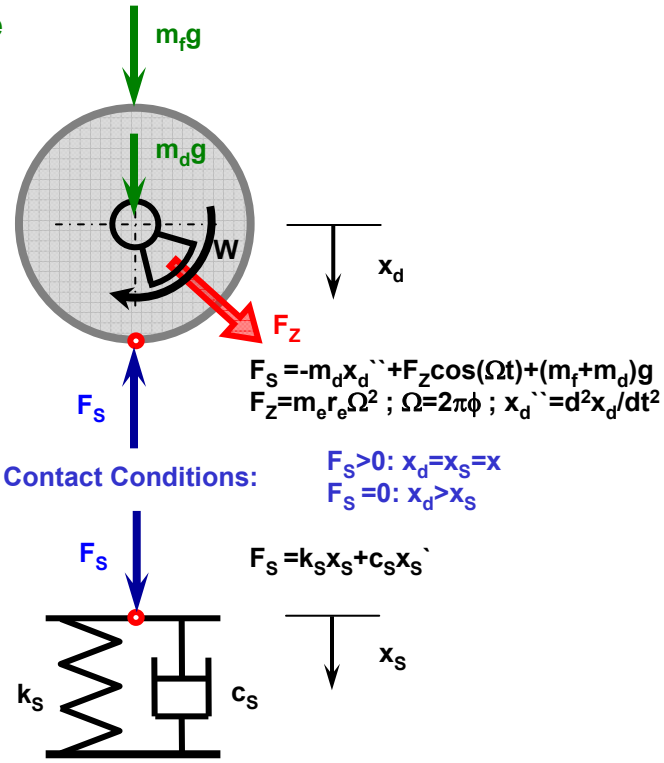
Soil

Force-Driven Nonlinearity

$$m_d \ddot{x}_d + F_B + c_G(\dot{x}_d - \dot{x}_f) + k_G(x_d - x_f) = m_u r_u \Omega^2 \cos(\Omega \cdot t) + m_d g$$
$$m_f \ddot{x}_f + c_G(\dot{x}_f - \dot{x}_d) + k_G(x_f - x_d) = m_f g$$

Simulation-Model

$$F_B = c_B \dot{x}_d + k_B x \quad \text{if } F_B > 0$$
$$F_B = 0 \quad \text{else}$$



$F_S = -m_d x_d'' + F_Z \cos(\Omega t) + (m_f + m_d)g$

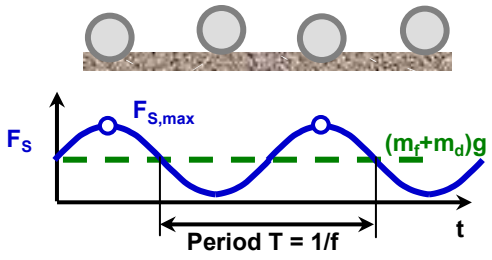
$F_Z = m_e r_e \Omega^2$; $\Omega = 2\pi\phi$; $x_d'' = d^2x_d/dt^2$

Contact Conditions:

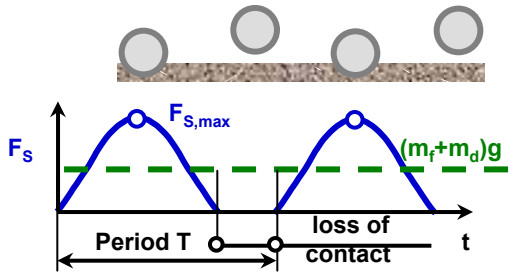
$F_S > 0$: $x_d = x_S = x$

$F_S = 0$: $x_d > x_S$

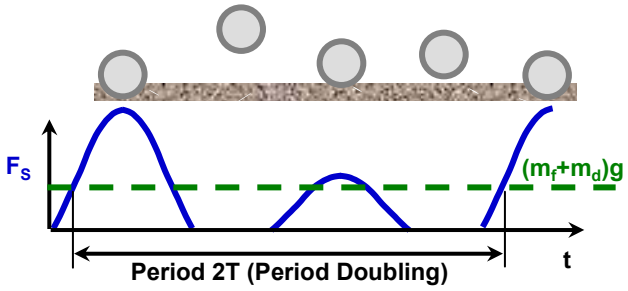
$F_S = k_S x_S + c_S x_S'$



$F_{S,max} < 2(m_f+m_d)g$: permanent Contact

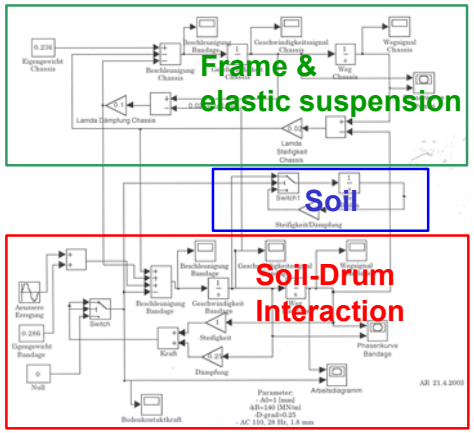


$F_{S,max} > 2(m_f+m_d)g$: periodic Loss of Contact



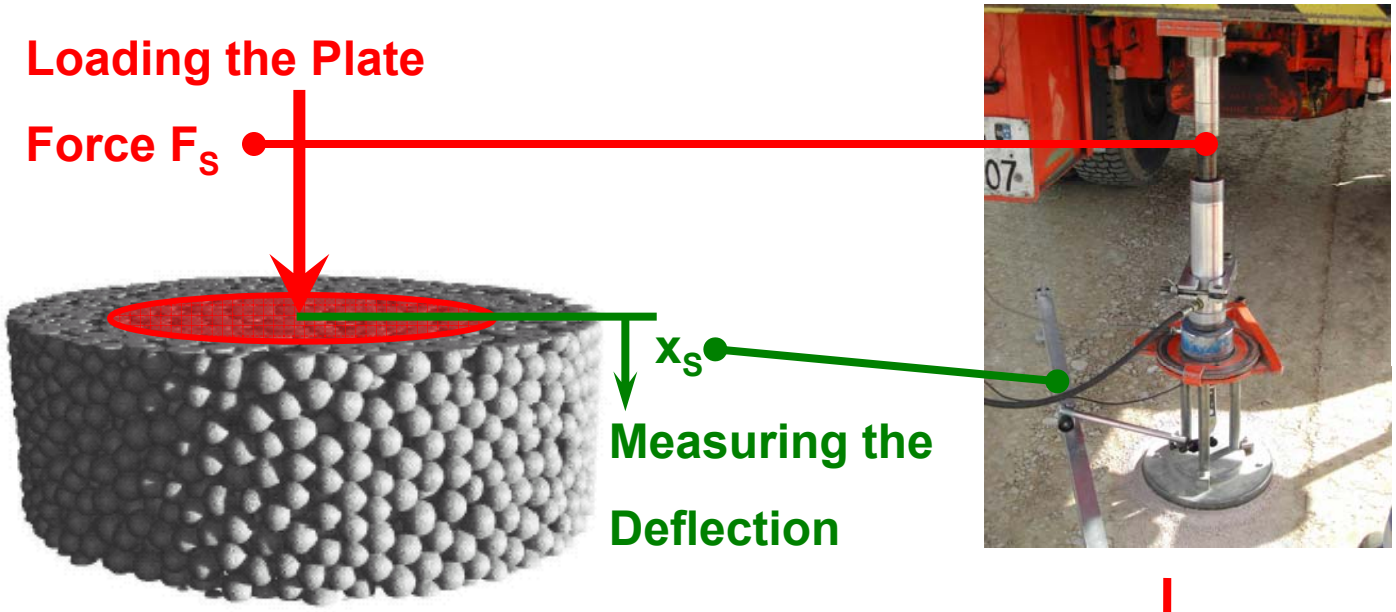
$F_{S,max} > 2(m_f+m_d)g$: double Amplitude, Bouncing

Nonlinear Dynamic Behavoir: Using a Simulation Tool [12]



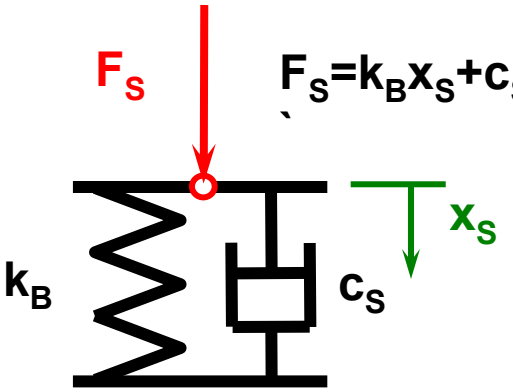
MathLab/Simulink-Model

ACE_{plus}: Measuring the Soil Compaction [10], [11]



Mechanistic Soil model:

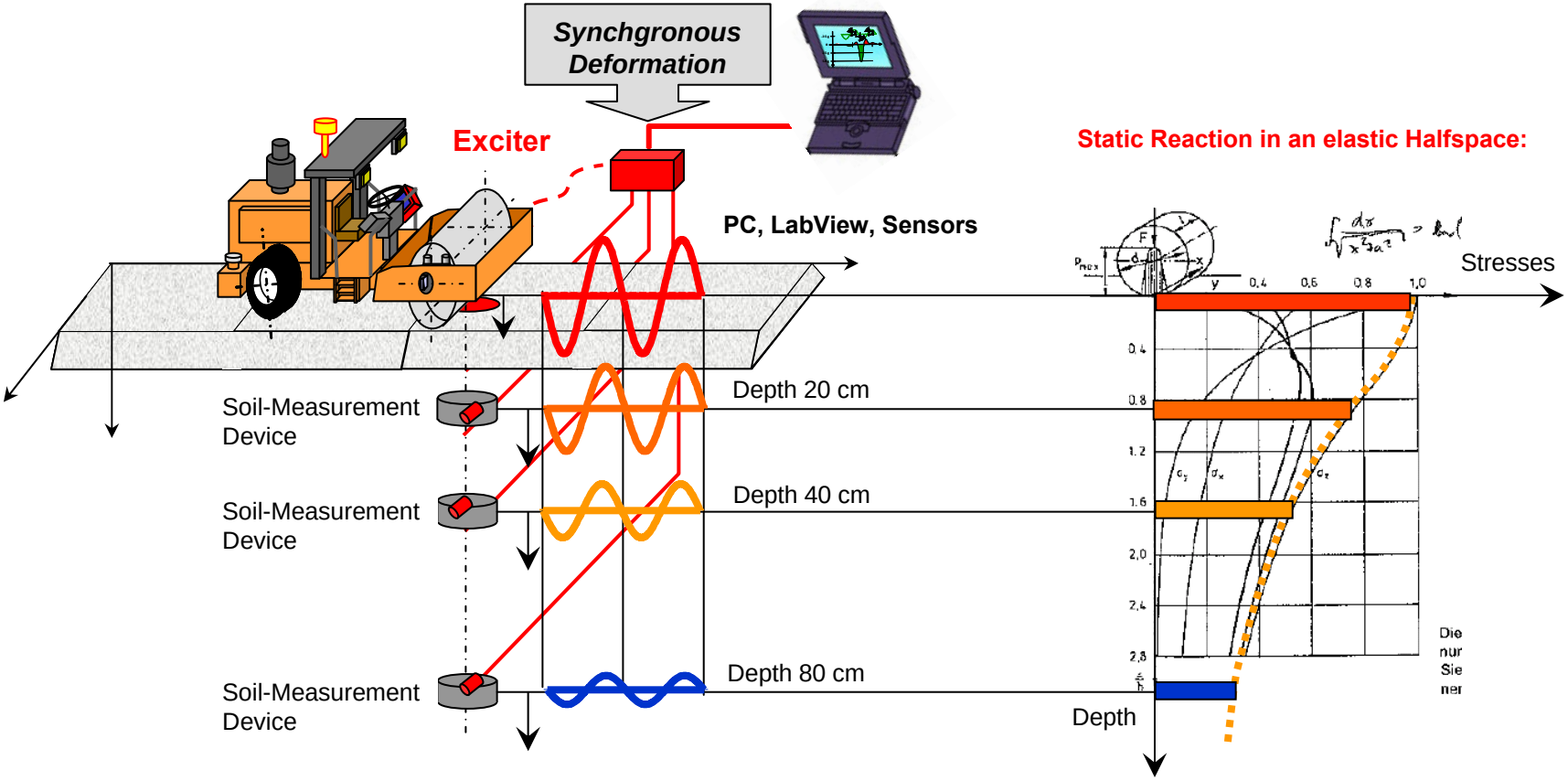
$$F_S = k_B x_S + c_S x_S$$



Stiffness of Soil:

$$k_B = \frac{F_S}{x_S}$$

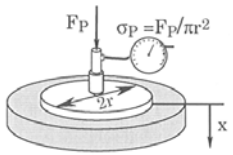
ACE$_{plus}$: Soil Stiffness –practical Validation [4], [13]

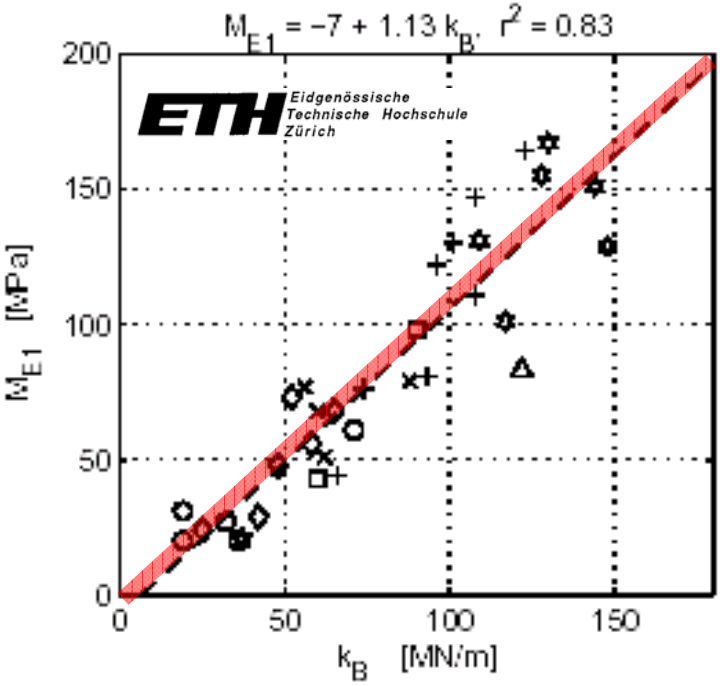


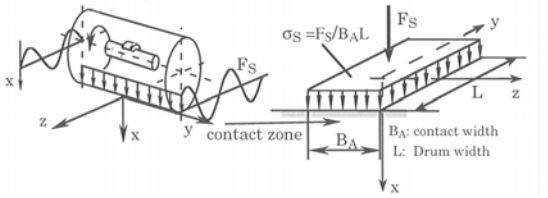
⇒ **the Soil/Drum-System vibrates near his lowest Resonance Frequency**

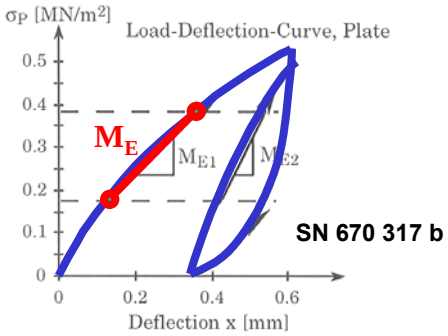
⇒ **the System reacts quasi-static like a Spring, complemented by a Dashpot**

Correlation with Plate Bearing Test [10], [11]



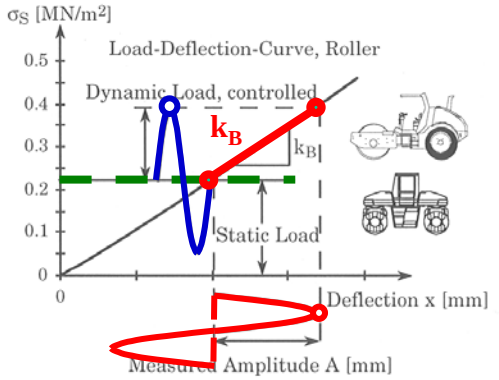




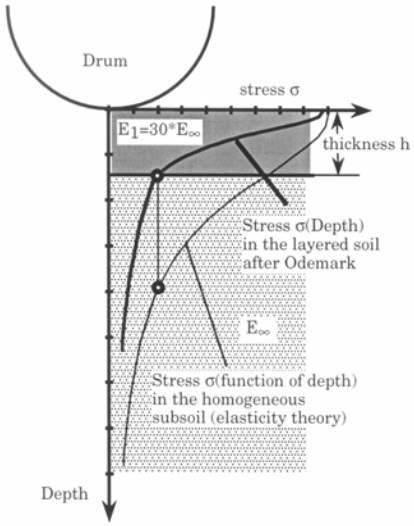


Adequate Testing

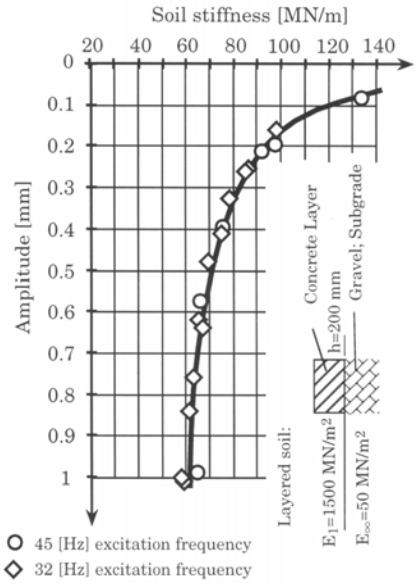
Plate Bearing Test → [1]

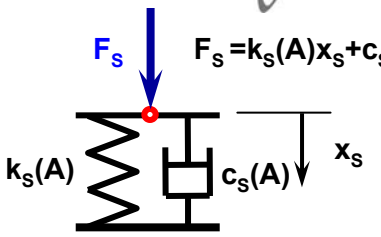


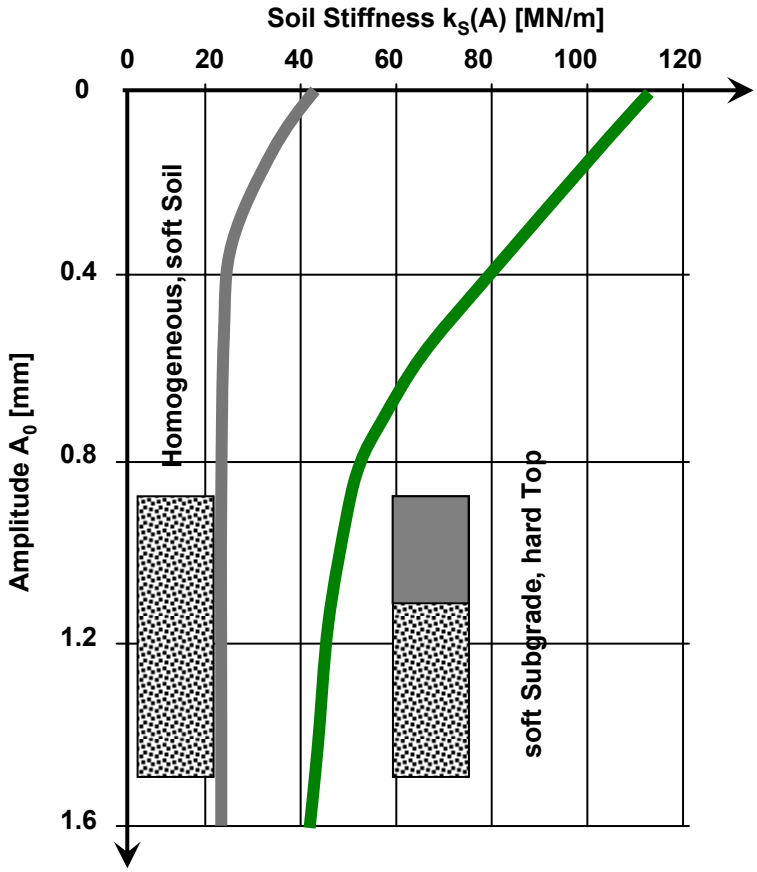
Layered Soil Measurement [4]



Layered Soils
- Odemark (1946)



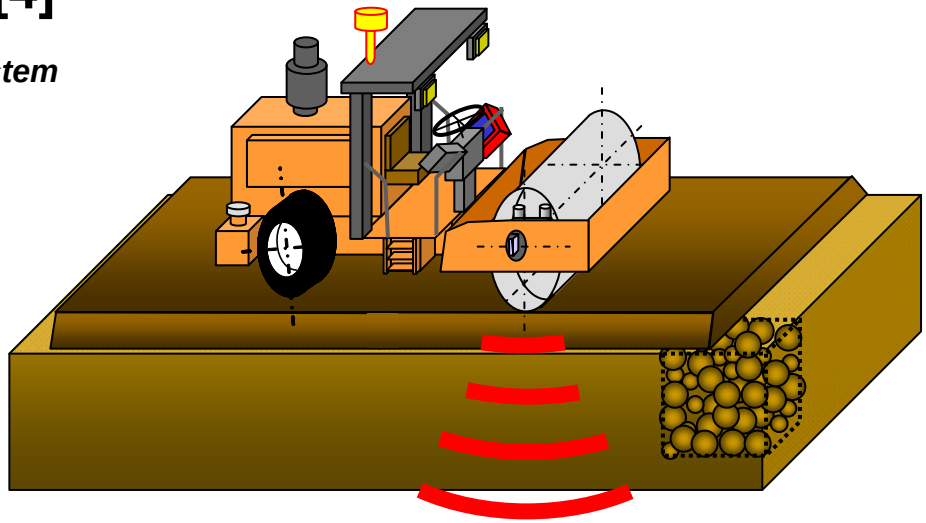




ACE$_{plus}$: Layered Soils [4]

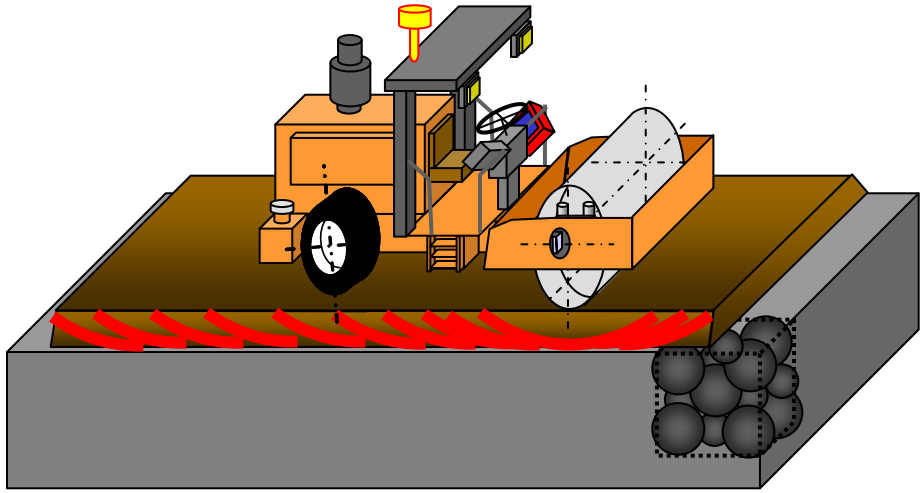
Measurement Depth of the ACE$_{plus}$-System

Loam, compacted; acting as a Spring



Measuring into the Subgrade

Measuring into the Subgrade



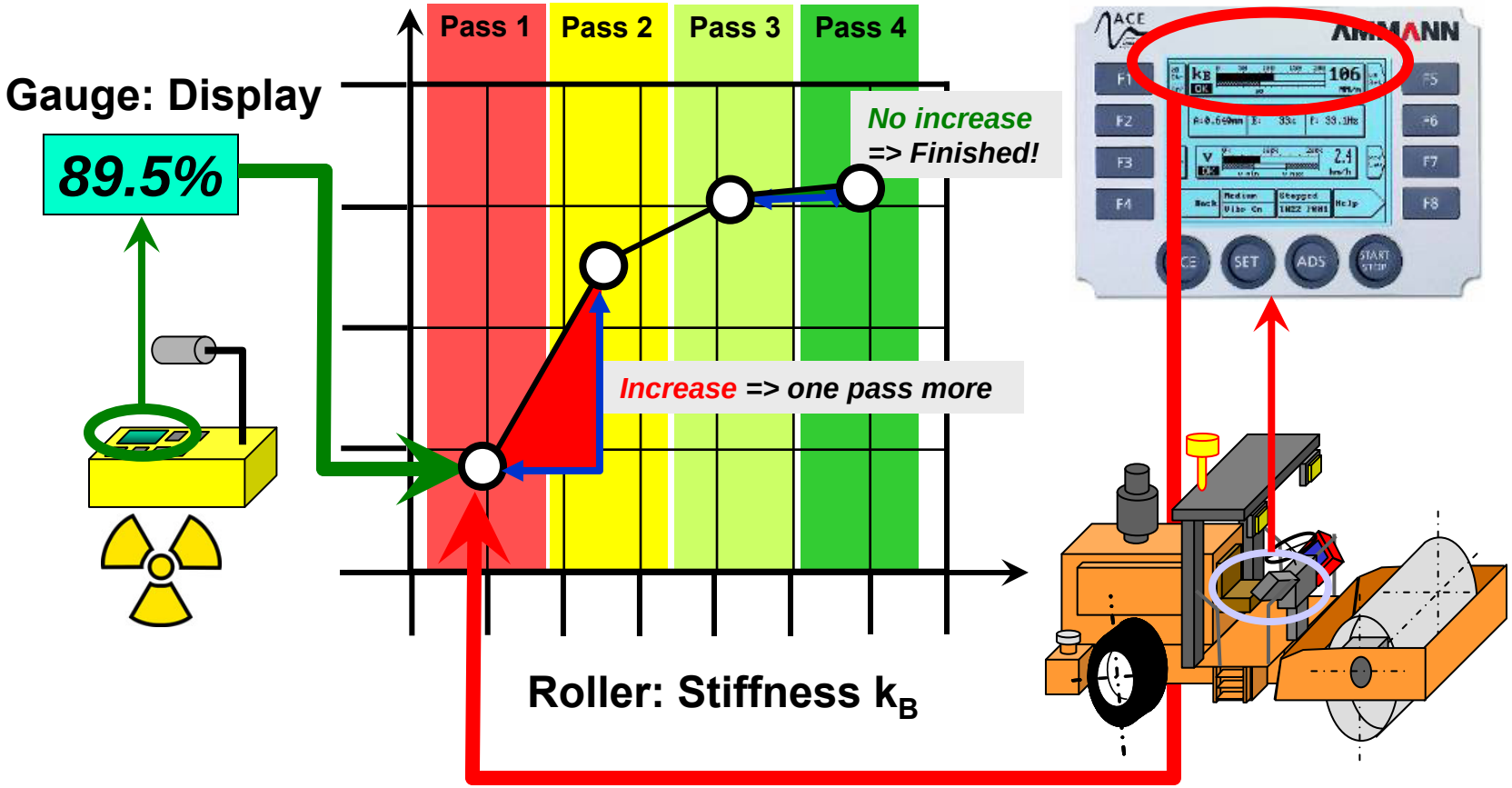
Gravelly Soil, well compacted; acting as an anvil

Measuring the Layer

Measuring the Layer

ACE$_{plus}$: Using the System in Practice

Combining the Pass Number and the Stiffness Improvment



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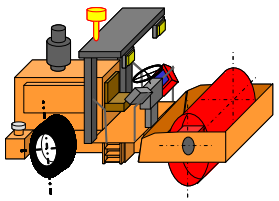
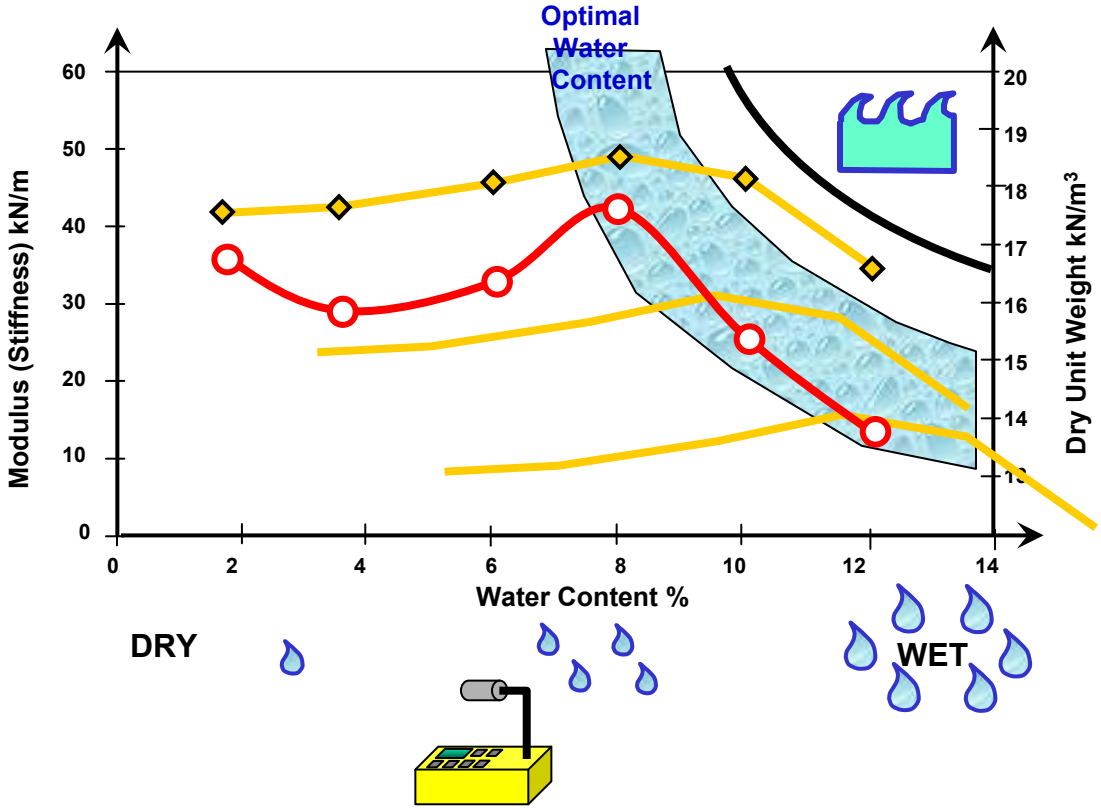
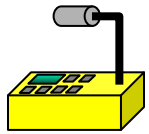
Spec‘s for Aggregates and Moisture Content [2]

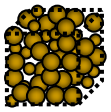
Correlation between Dry Unit Weight and Stiffness/Bearing Capacity





Coarse Grain: Gravel





Fine Material: Loam

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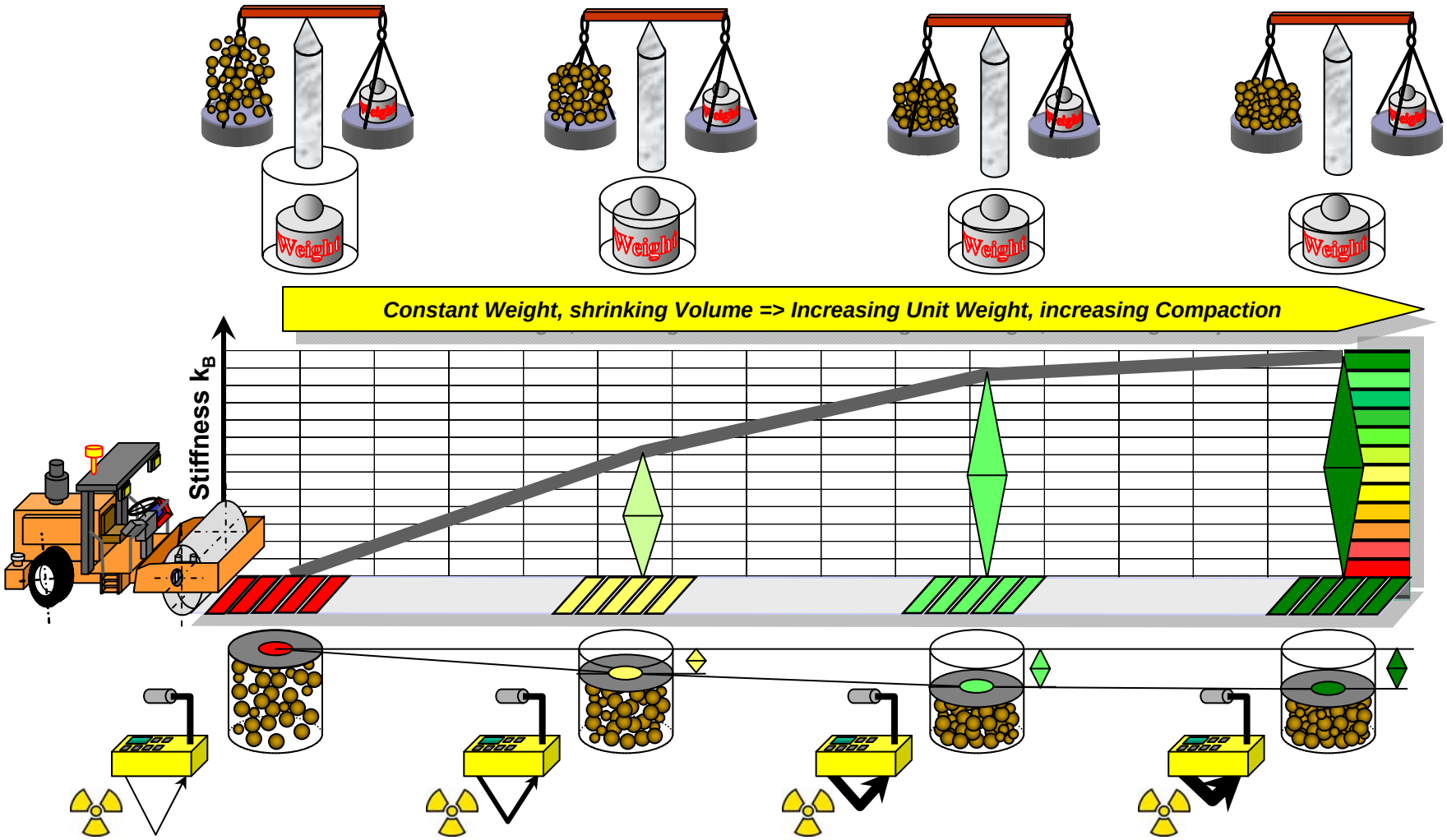
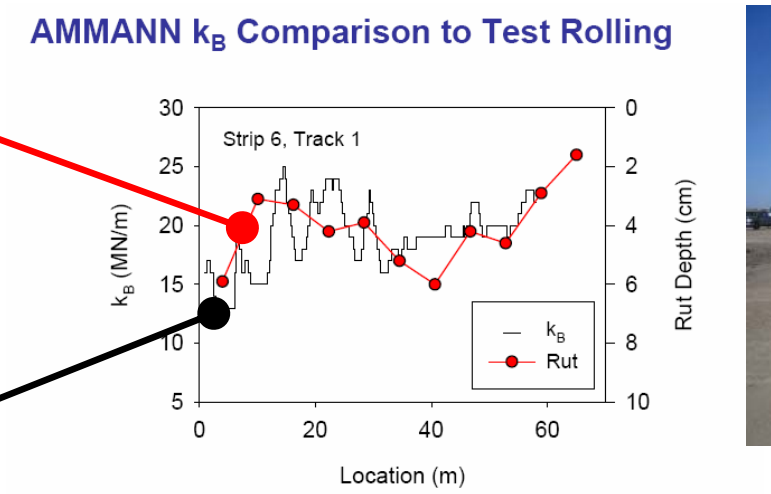
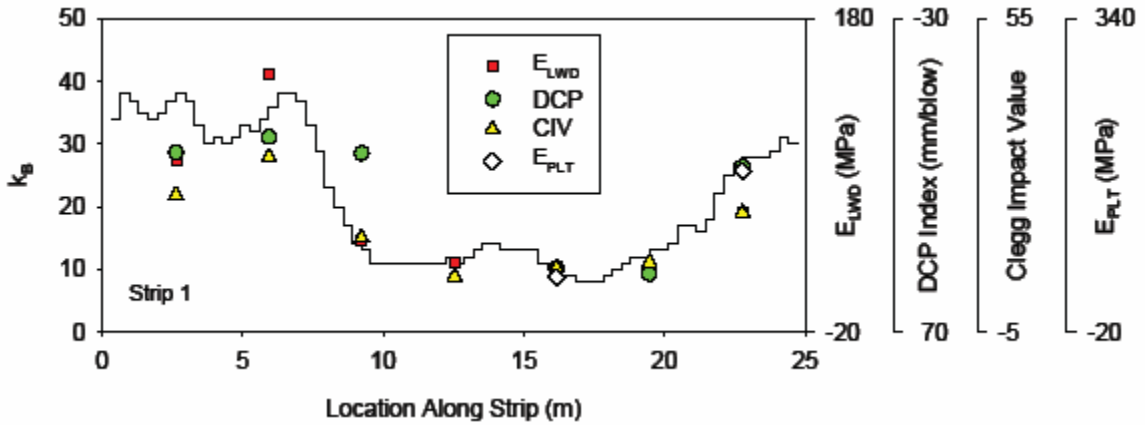
Compaction, Density, Dry Unit Weight & Stiffness



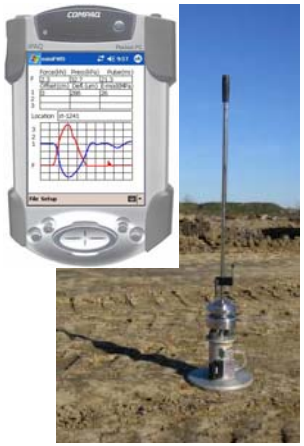
MN DOT: Testing ACE Measurement [8], [9]

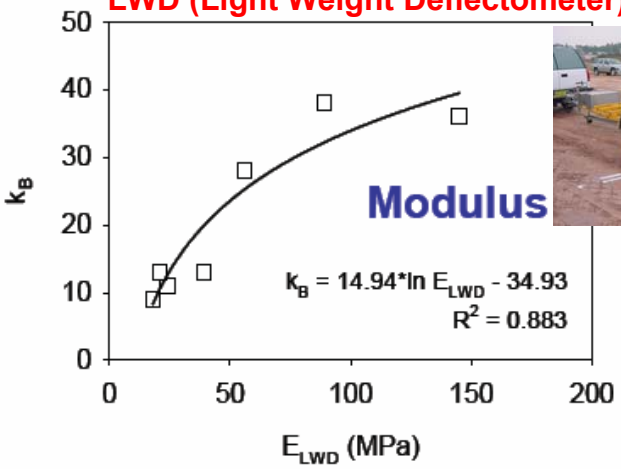
Mankato MN, 2005

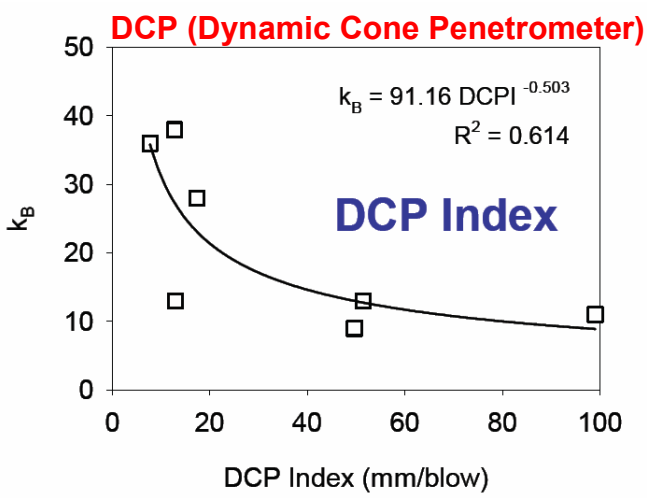


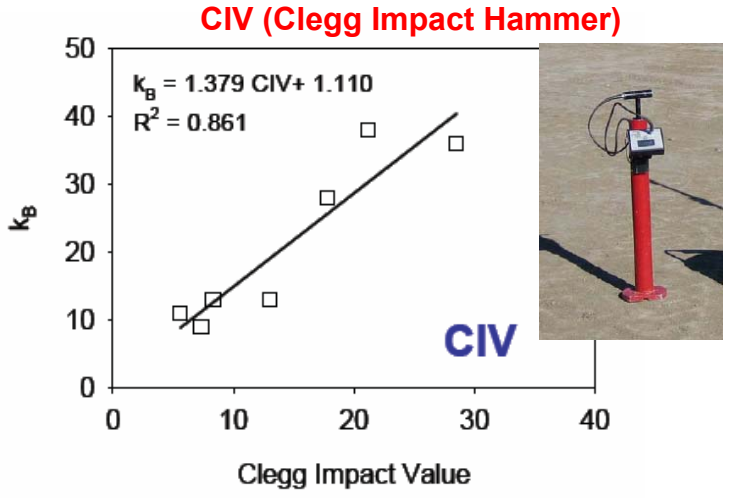


Correlation ACE k_B and U.S. Test Data [8]

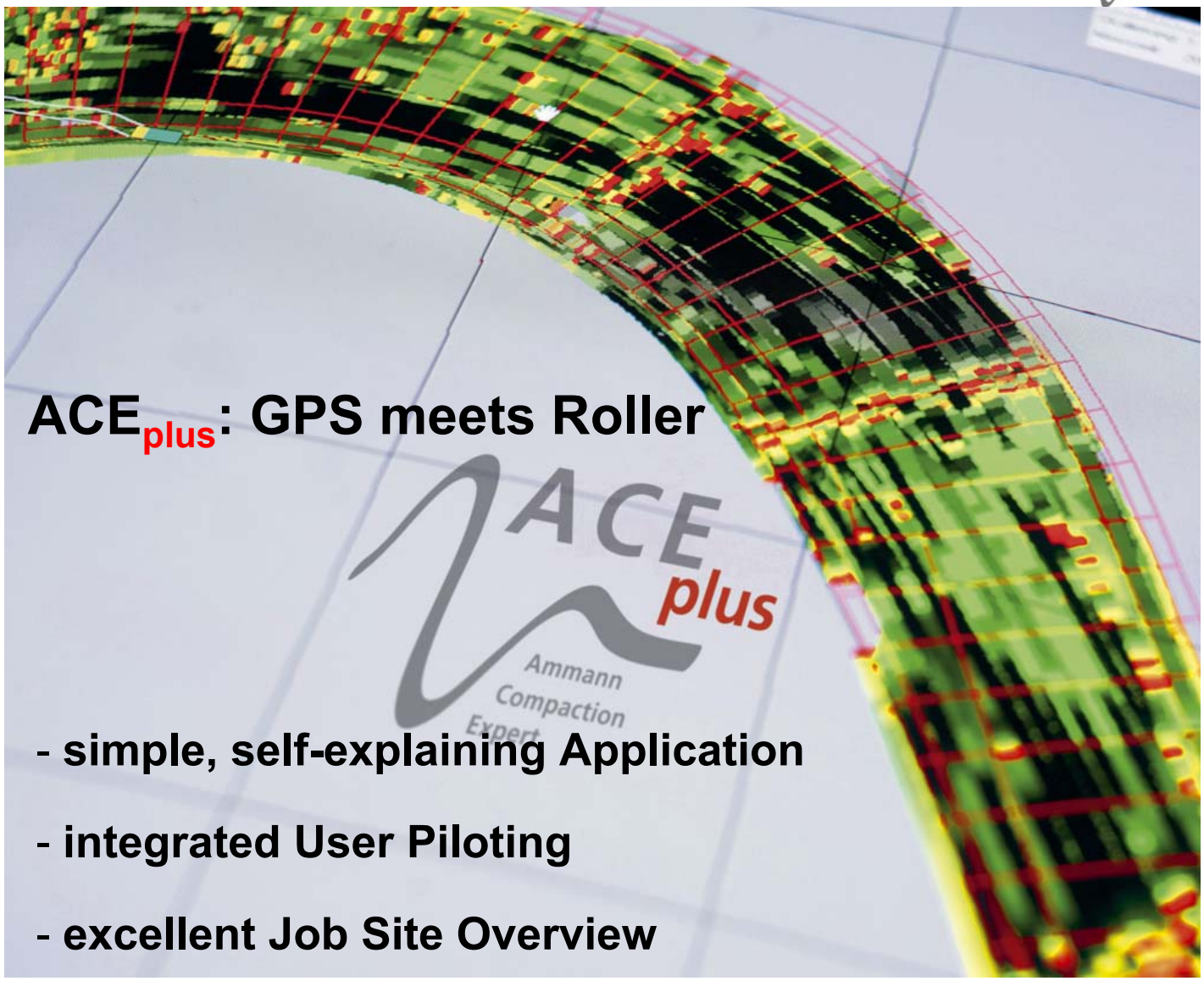








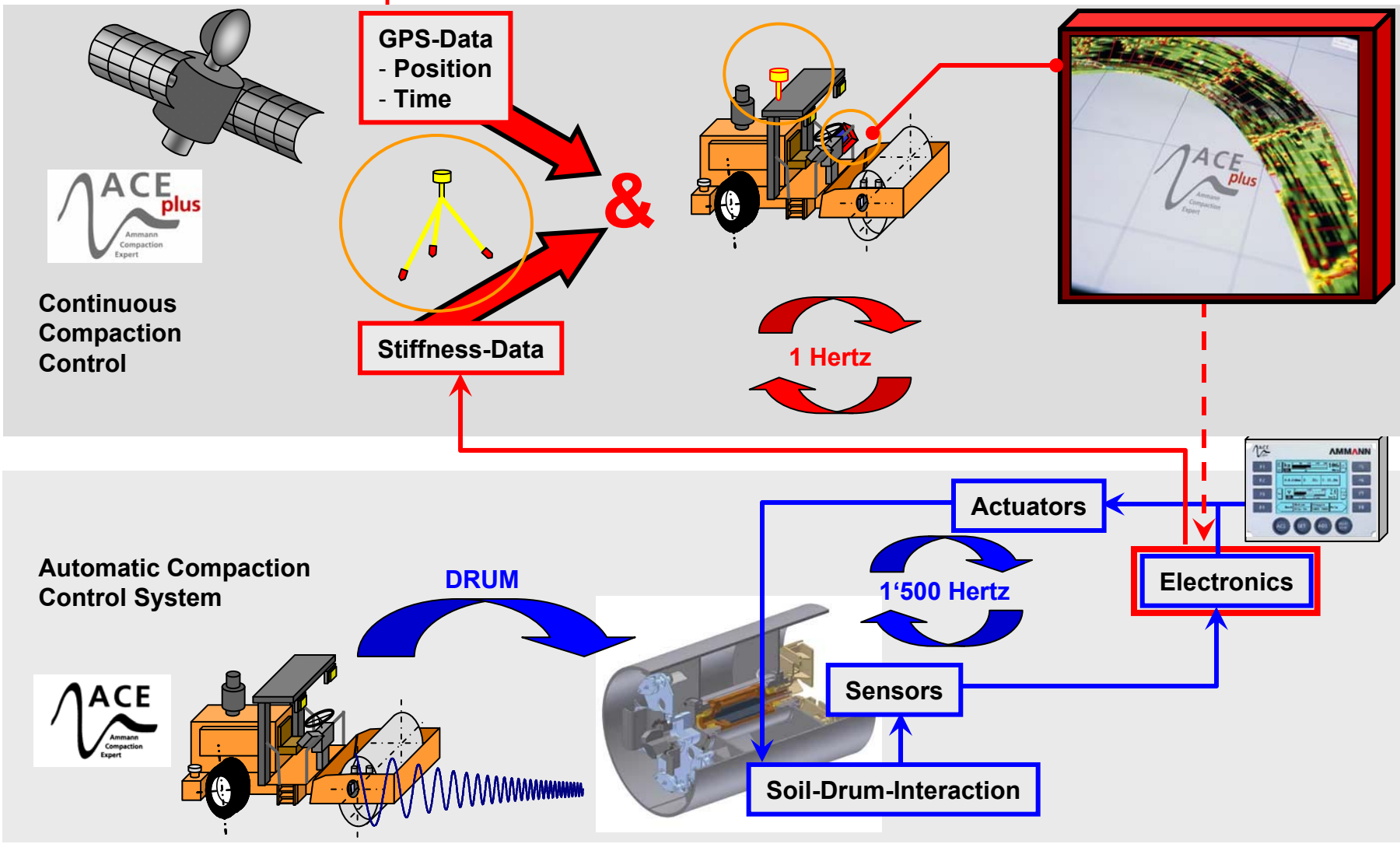
ACE plus



ACE$_{plus}$: GPS meets Roller

- simple, self-explaining Application
- integrated User Piloting
- excellent Job Site Overview

ACE$_{plus}$: Two Control Loops are interacting

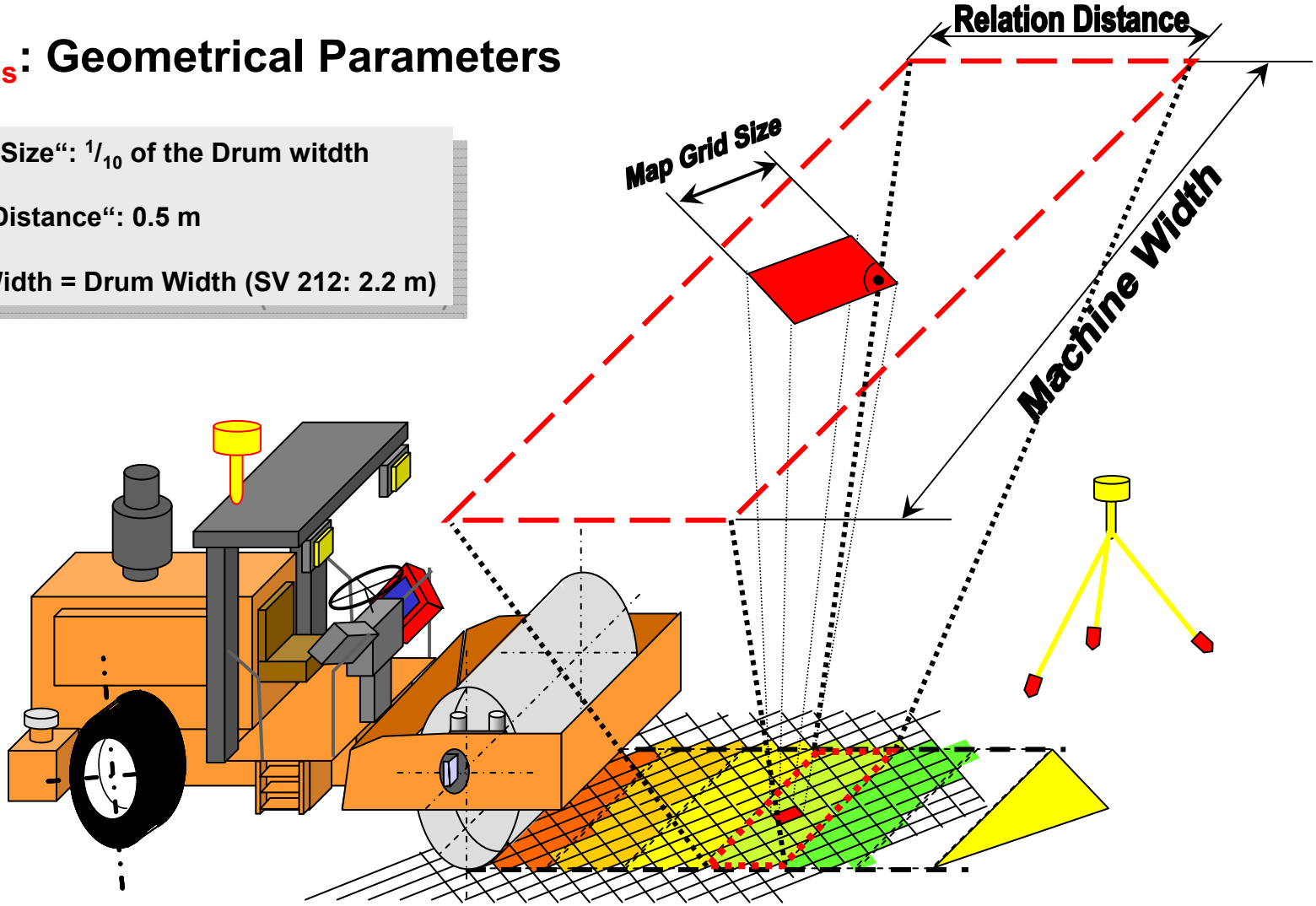


ACE$_{plus}$: Geometrical Parameters

„Map Grid Size“: $^{1}/_{10}$ of the Drum witdth

„Relation Distance“: 0.5 m

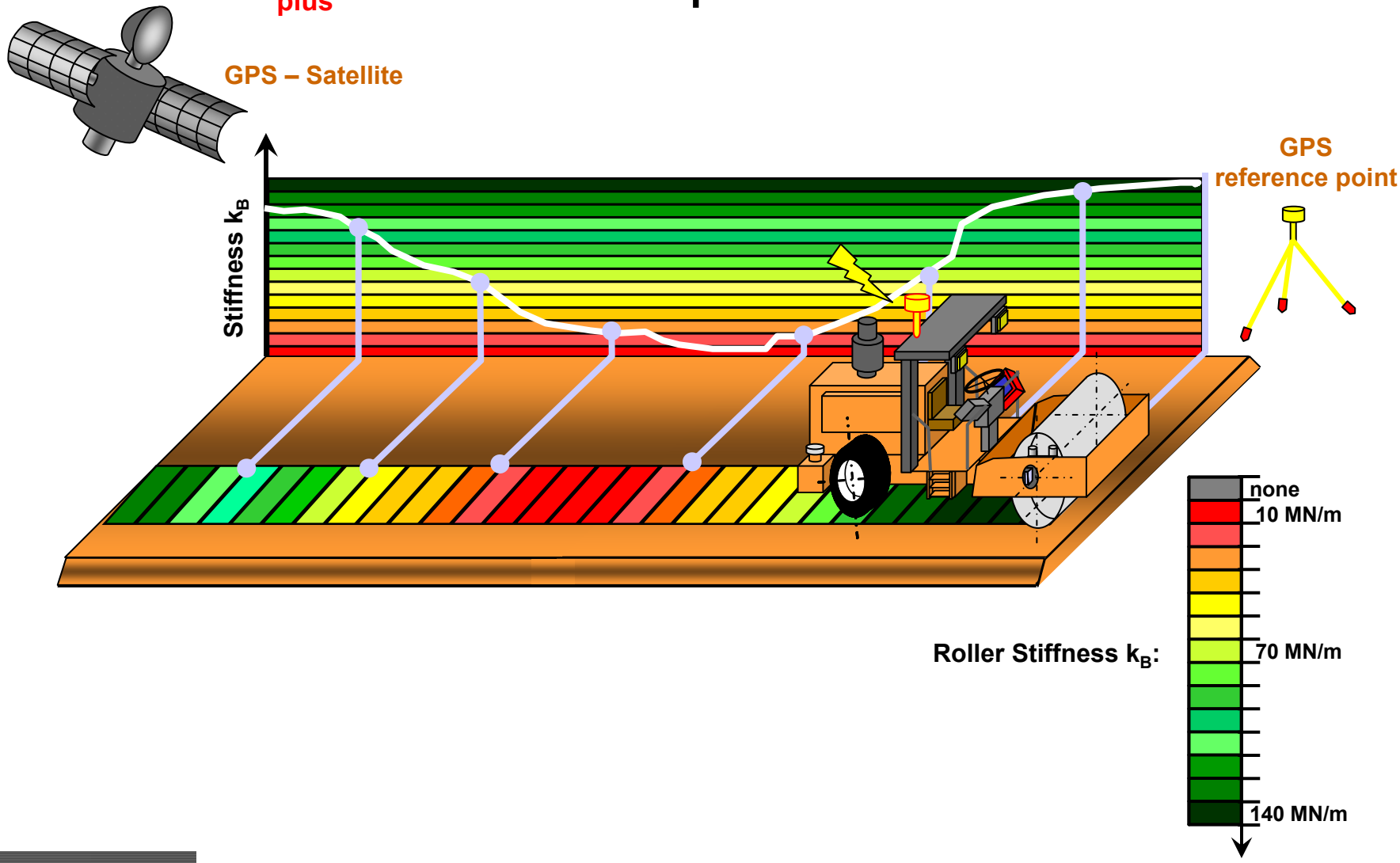
Machine Width = Drum Width (SV 212: 2.2 m)



Intelligent Compaction

ACE plus

ACE$_{plus}$: GPS-based Compaction Measurement



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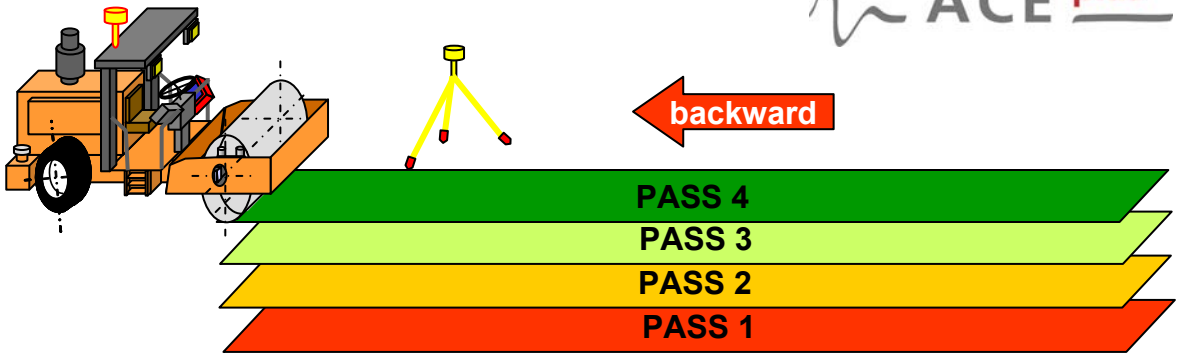
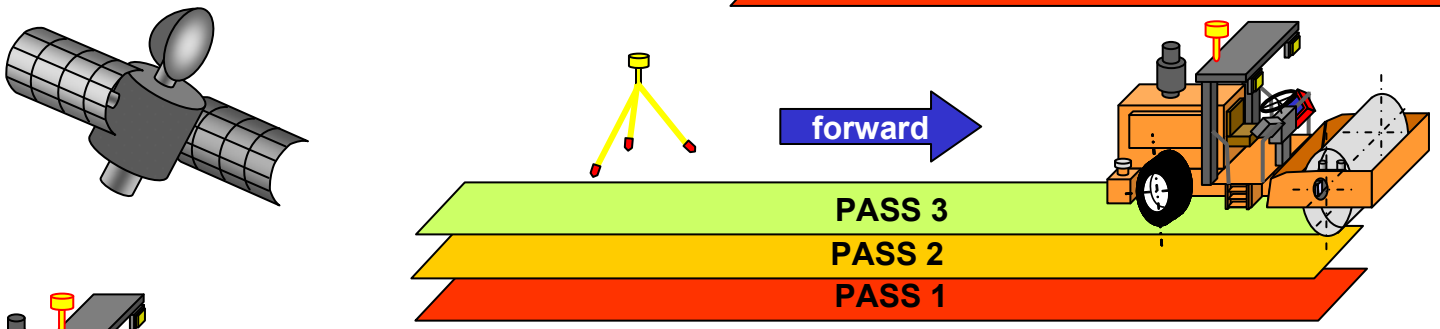
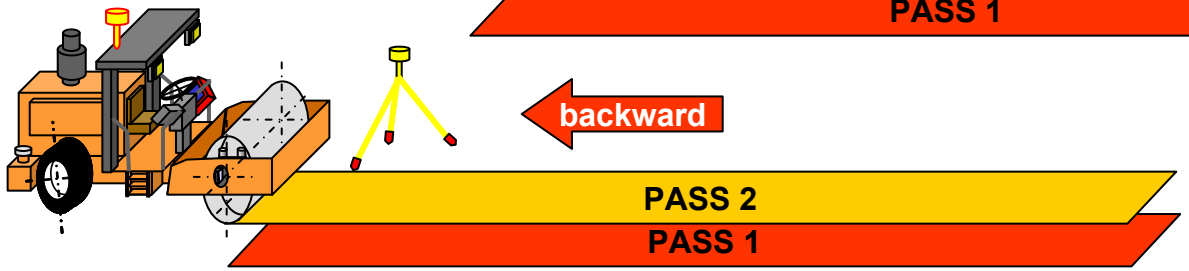
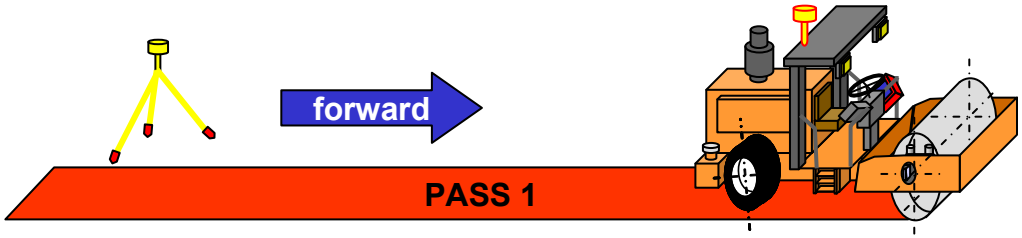
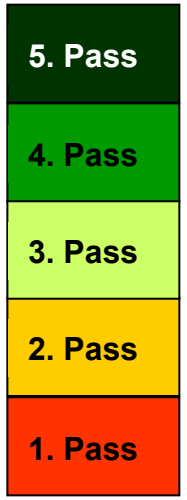
ACE$_{plus}$: Counting the Passes











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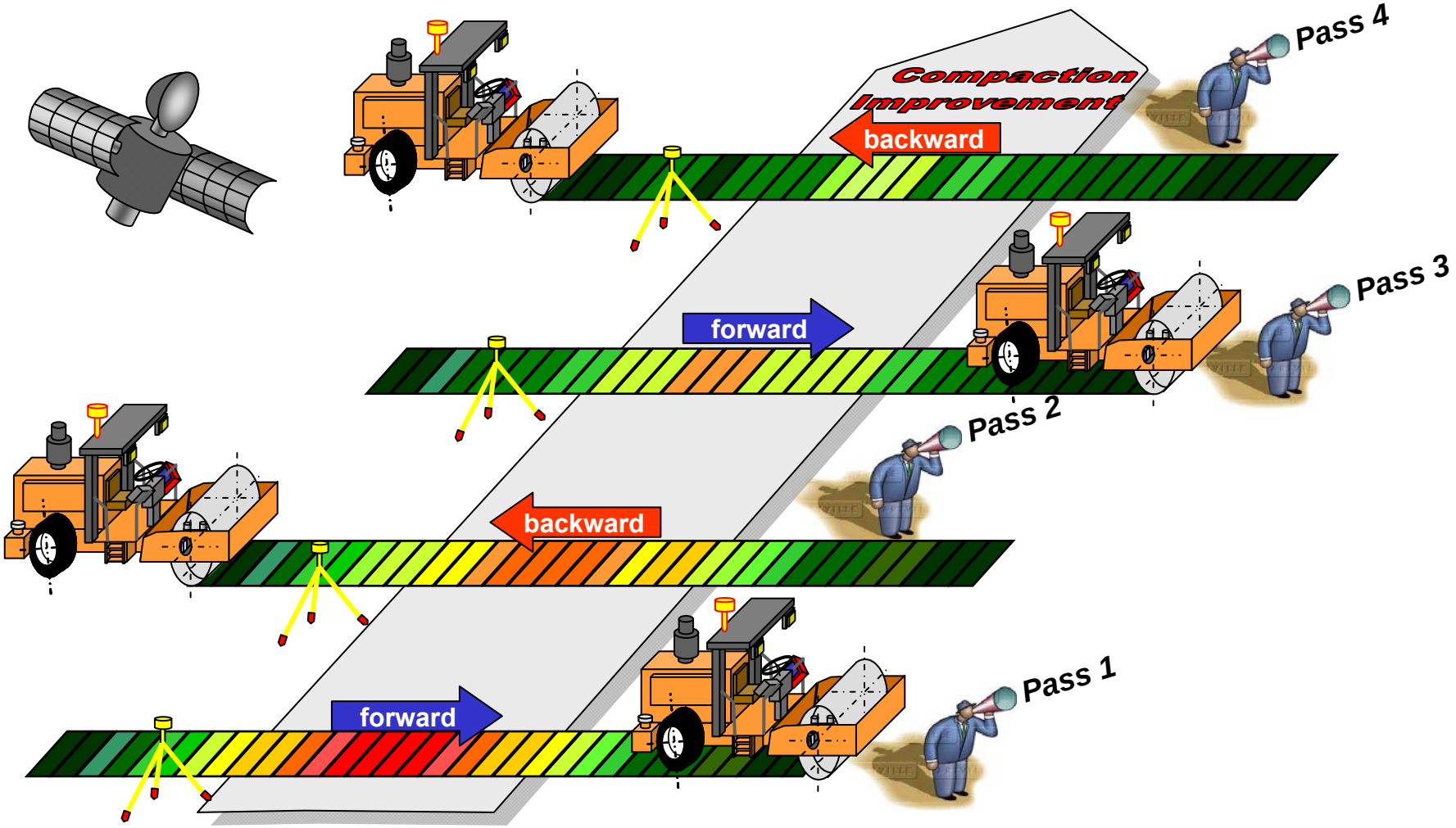
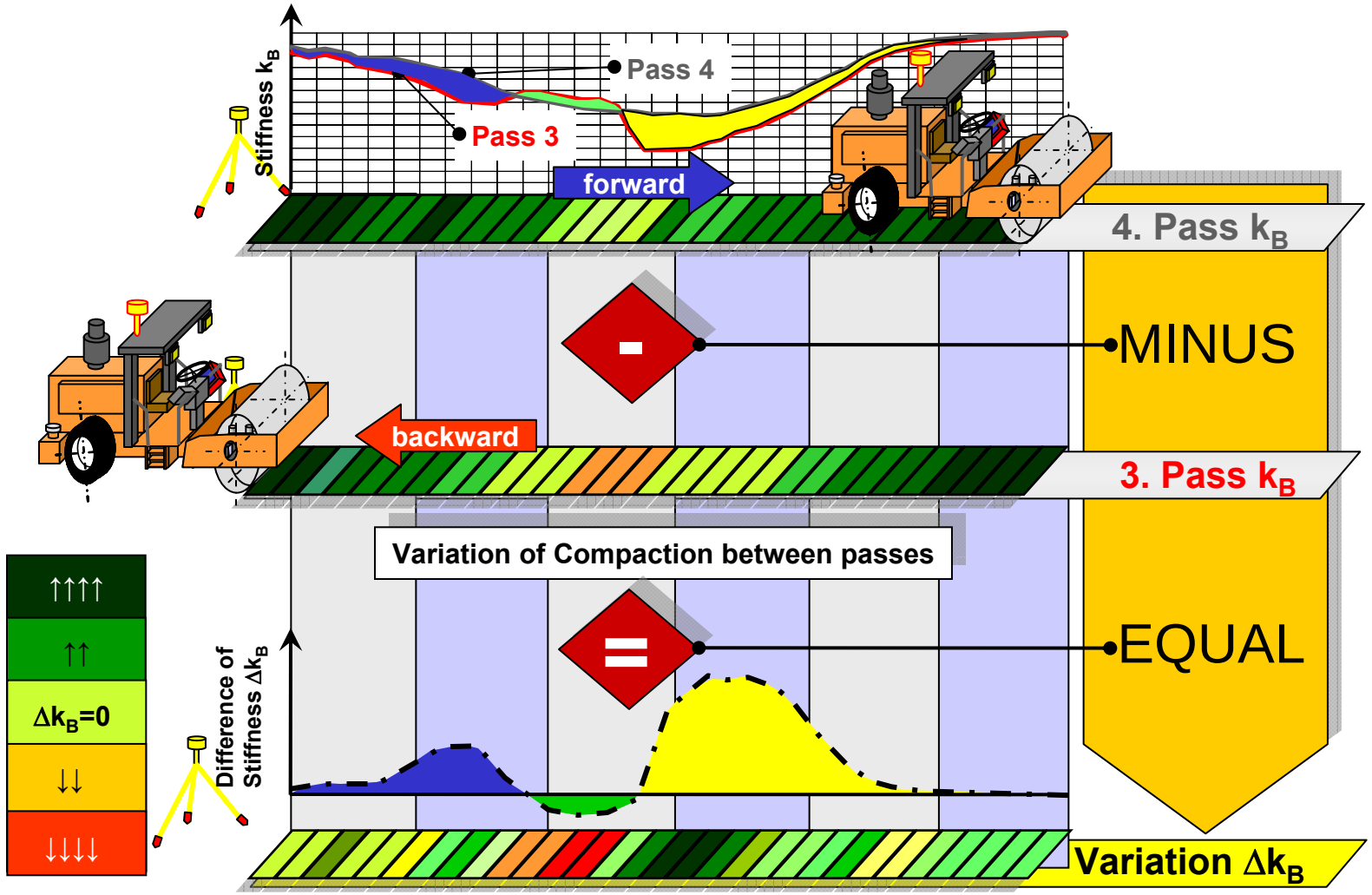
ACE$_{plus}$: Process Control - increasing Compaction Values



ACE plus

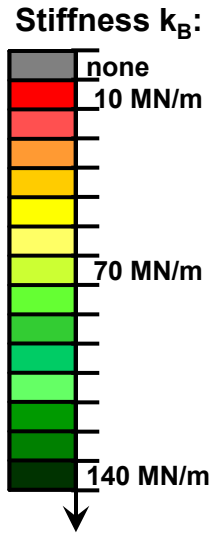
ACE$_{plus}$: Checking the Compaction Development

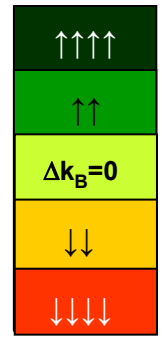


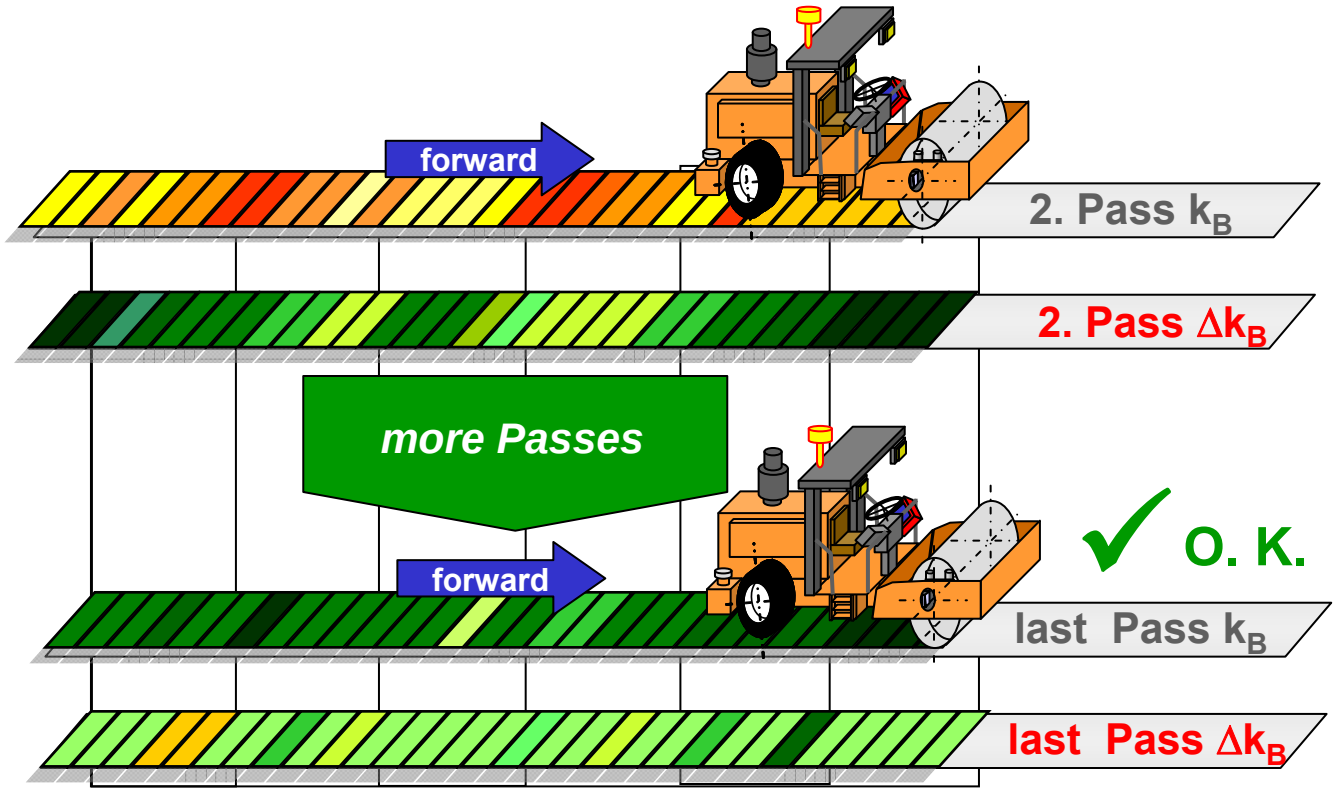
Intelligent Compaction

ACE plus

ACE$_{plus}$ shows: *Good* Compactibility of Soil Material







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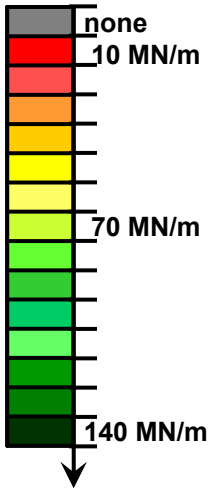
Intelligent Compaction

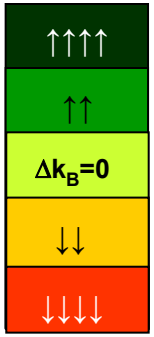
ACE plus

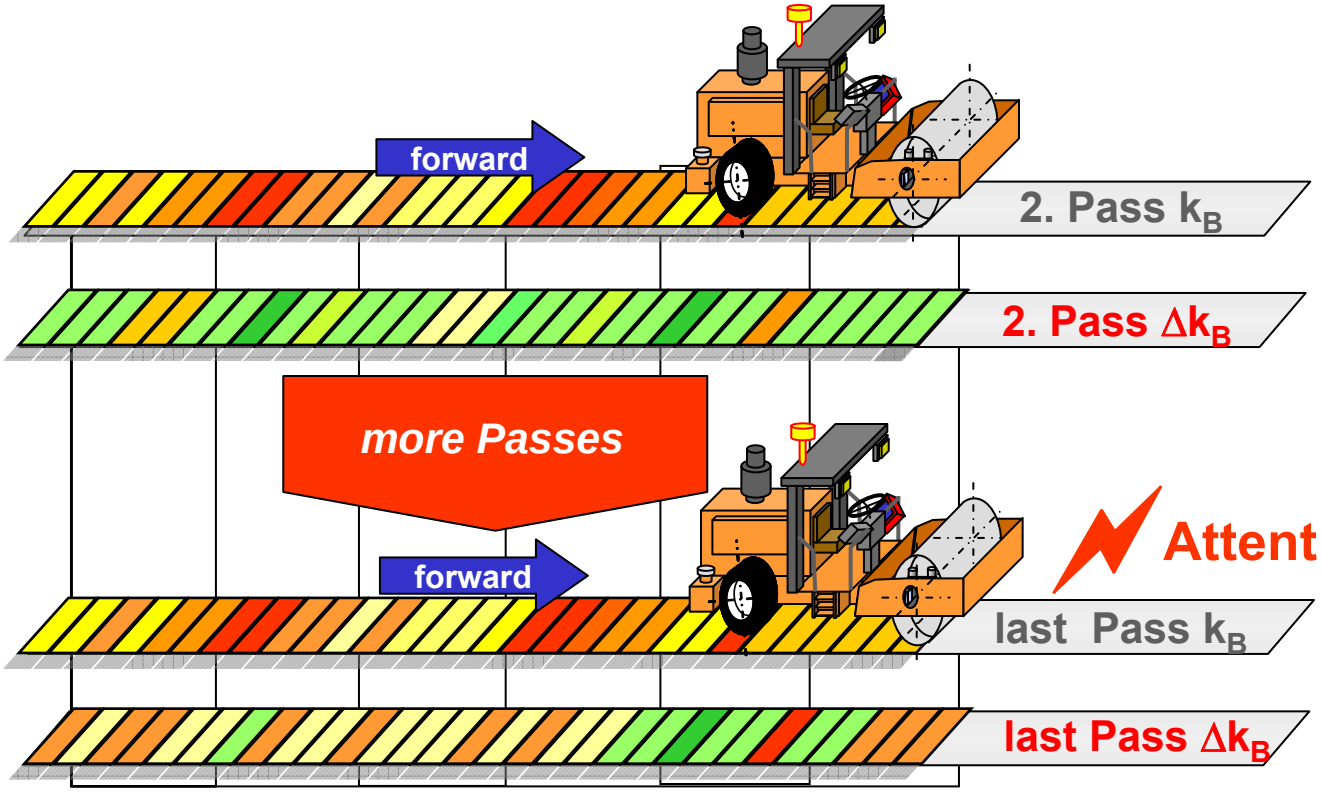
ACE$_{plus}$ shows: *Bad* Compactibility of Soil Material

Stiffness k_B:



ΔStiffness Δk_B:





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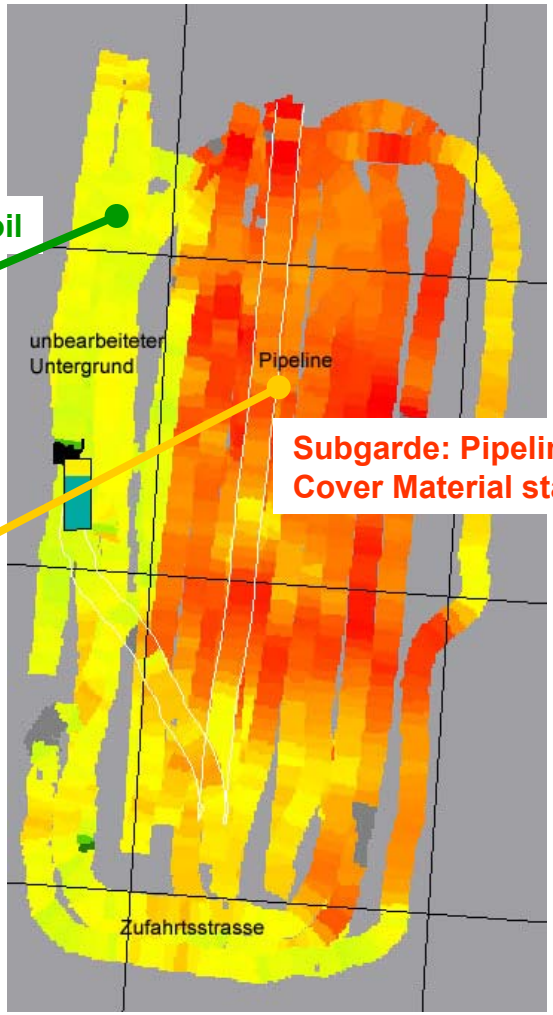
ACE$_{plus}$: Compacted Soil Different Subgrade

Well compacted Soil

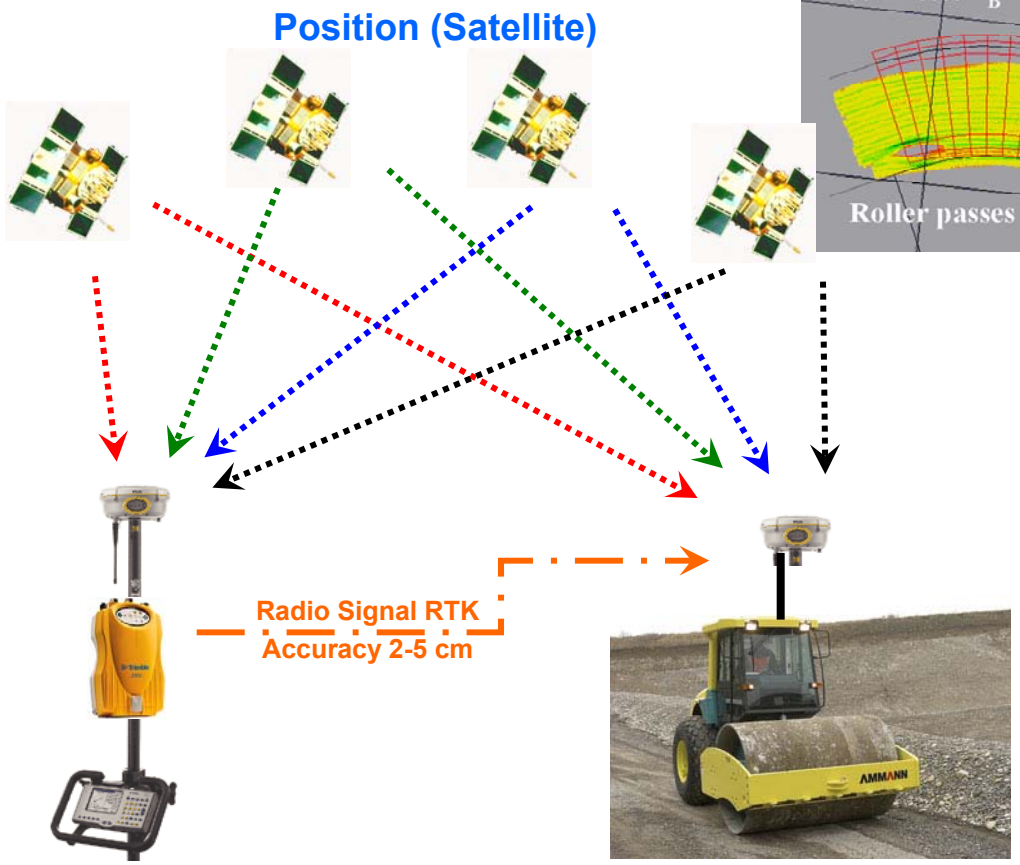


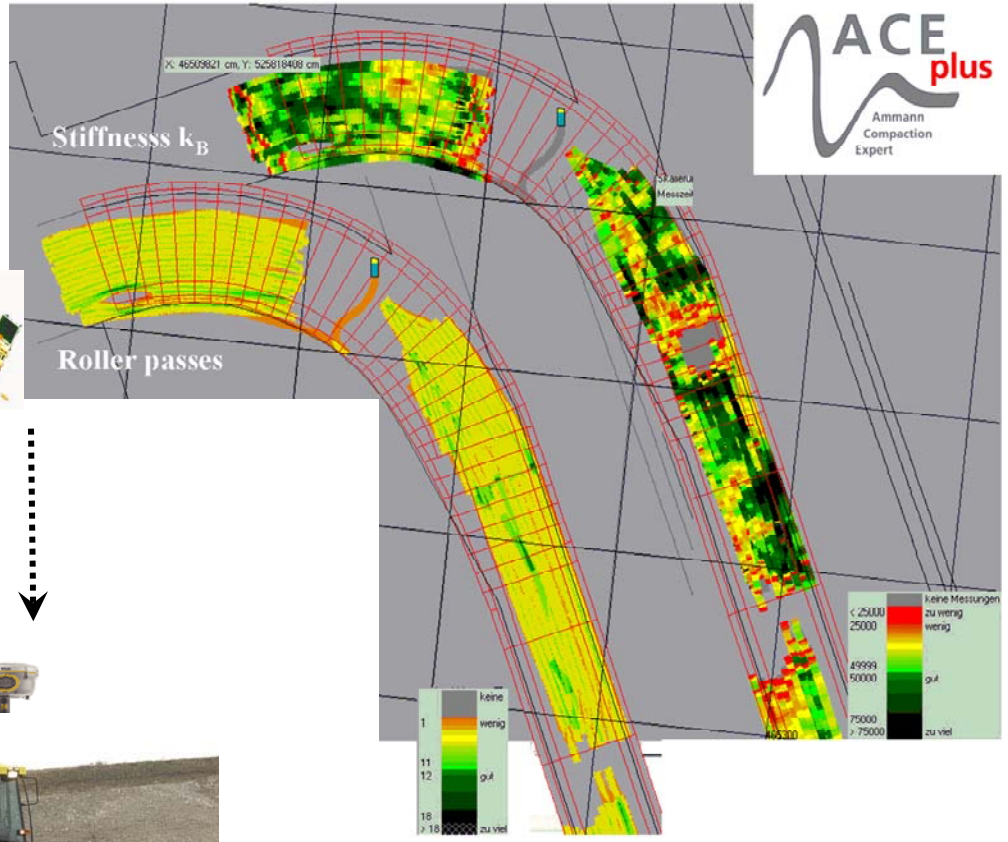
Subgarde: Pipeline
Cover Material stays soft

Intelligent Compaction

ACE plus

ACE$_{plus}$ in Soil Compaction...





...on a Airport Job Site [10]

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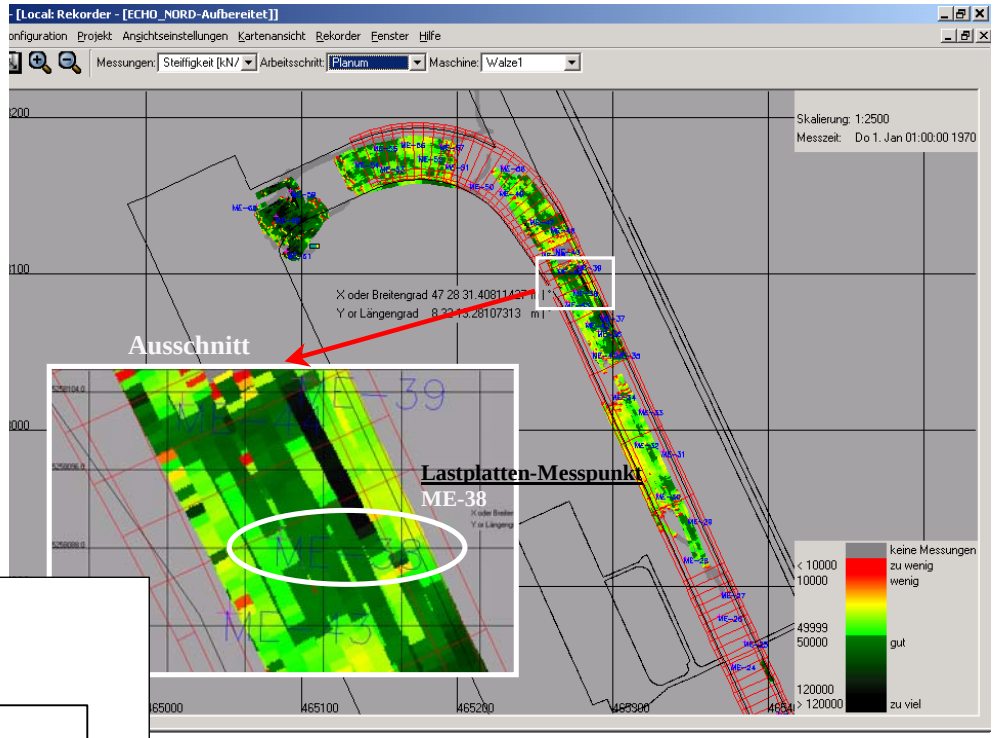
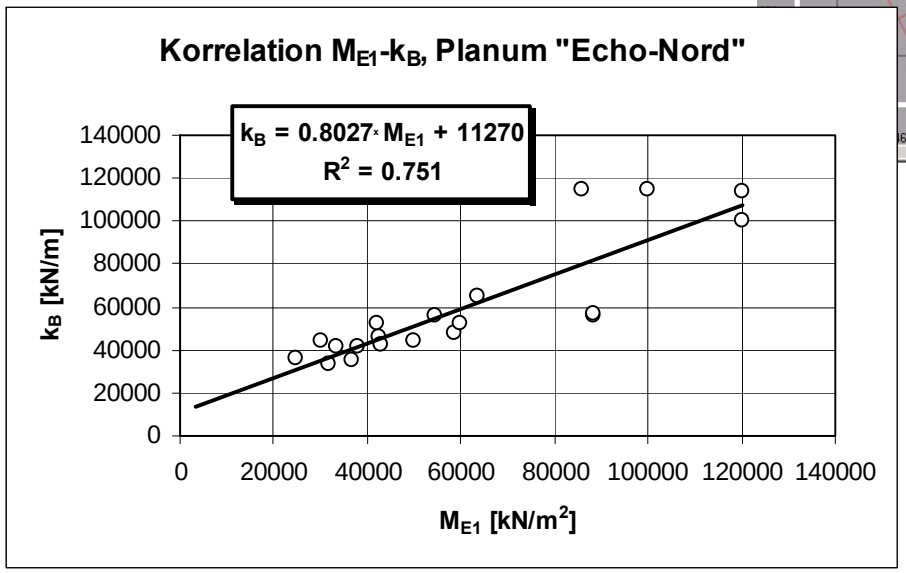
Correlation [10]

- Single Drum Roller with GPS Position
- Plate Bearing Test [1] with GPS Position





$$k_B\left[\frac{MN}{m}\right] = 0.8 \cdot M_{E1}\left[\frac{MN}{m^2}\right] + 11.3$$

- Soft Subsoil
- one Layer of well graded Material

Intelligent Compaction (Benefits for the Customers)

1. Optimized/Maximized Productivity

- Feedback Control System: Automatic Adjustment of Compaction Energy (Amplitude, Frequency, Impact Spacing)
- Process-Integrated Measurement of Soil Stiffness

=> Easy to operate

2. Sustainable Compaction

- Homogeneous, optimal Compaction Results
- Continuous Compaction Control (GPS)