MAÚT Mérnökakadémia
Útépítés és geotechnika – szabályok és tapasztalatok
MAKADÁM-Klub
Budapest, Lövőház u. 15.
21. november 2007

Földművek tervezése, minőségbiztosítása és monitoringja Ausztriában

Standardization, Design, Quality Assurance and Monitoring of Earth Works in Road Engineering in Austria

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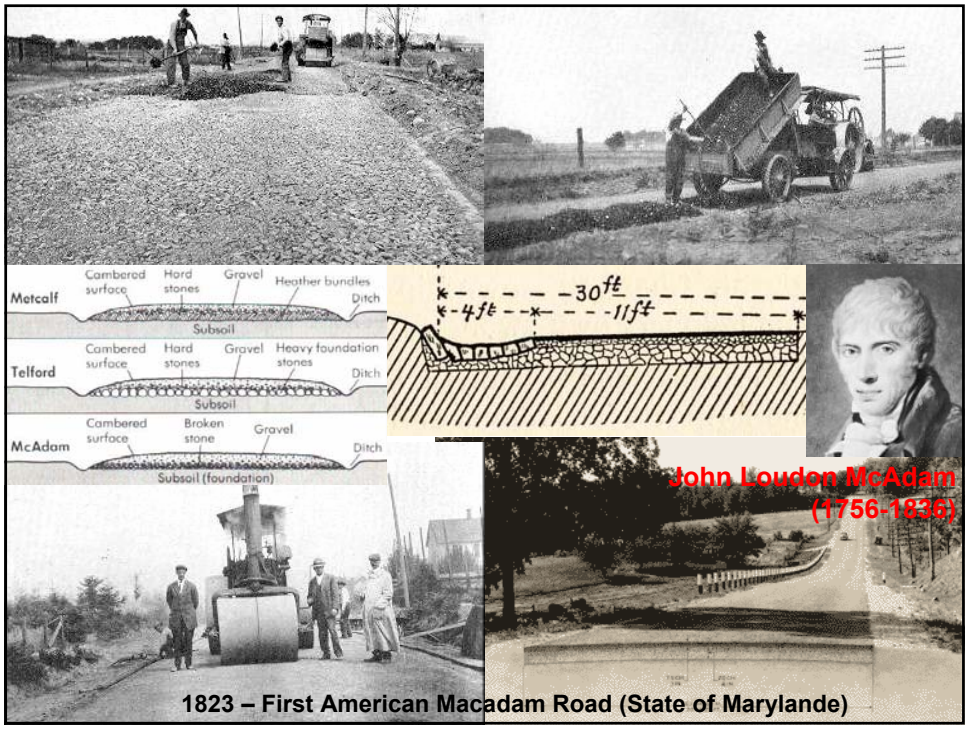
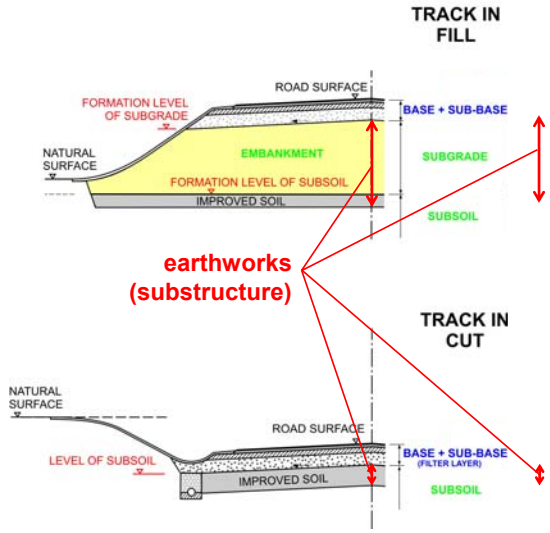
A-2345 Brunn am Gebirge



1823 – First American Macadam Road (State of Marylande)

[RVS 8.24] ⇨ RVS 08.03.01 [draft]

„Earthworks“ „Earthworks under Traffic Routes“

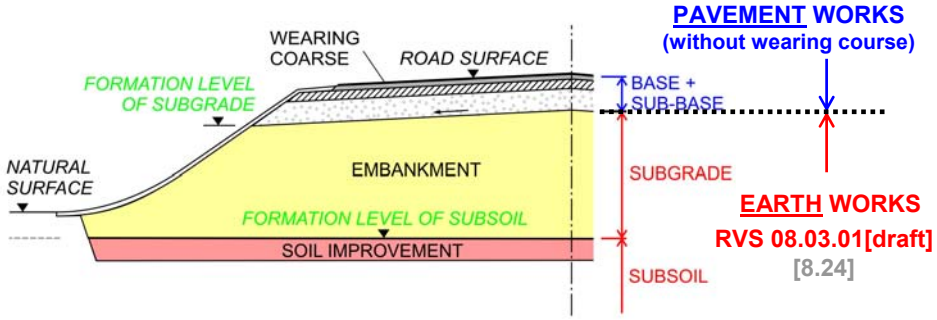


Cross Section – Definitions and Standards

RVS 08.15.01 [8S.05.11]: base and sub-base layer

RVS [8S.05.12]: mechanical stabilized base / sub-base layer

RVS 08.17.01 [8S.05.13]: with binder stabilized base / sub-base layer

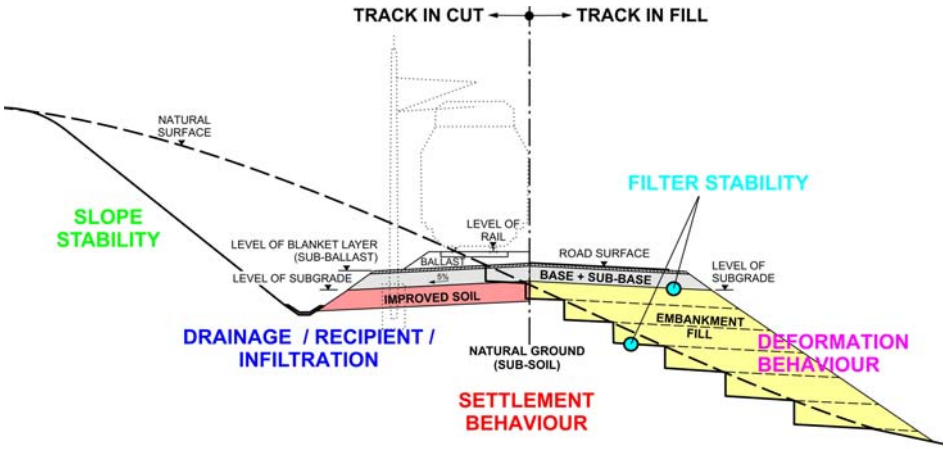


ÖNORM B 4417: static load plate test

RVS 08.03.04: compaction control with the dynamic load plate (LFWD)

RVS 08.03.02 [8S.02.06]: continuous compaction control (CCC)

Traffic Route – Requirements



strength & stability
+ serviceability ⇨ **COMPACTION**
+ durability

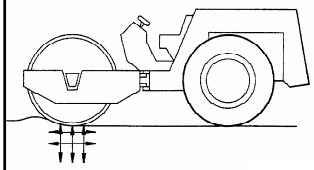
Methods of Ground / Fill Improvement

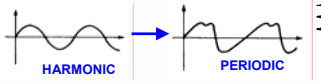
1	**Ground COMPACTION**	surface-near compaction
2	**Ground REPLACEMENT**	soil excavation and soil exchange
3	**MECHANICAL Improvement**	Mixing in suitable granular material to improve poorly graded materials (SP, GP), fine materials (silty or clayey) or soft soils
4	**Ground REINFORCEMENT**	reinforcement with geotextiles: in combination with soil replacement to reduce excavation depth
5	**Ground STABILIZATION**	stabilization with lime (ÖN EN 14227-11), cement (ÖN EN 14227-10), clinker (ÖN EN 14227-12), hydraulic binder (ÖN EN 14227-13), fly ash (ÖN EN 14227-14)
6	**DEEP IMPROVE-MENT OF SUBSOIL**	▪ surcharging and preloading ▪ vertical drains ▪ deep vibro compaction (RSV/RDV) ▪ Deep Dynamic Compaction (DYNIV) ▪ pile foundation

Surface-near and Deep Ground Improvement

Dynamic roller compaction

vibratory, oscillatory, VARIO, automatically controlled rollers

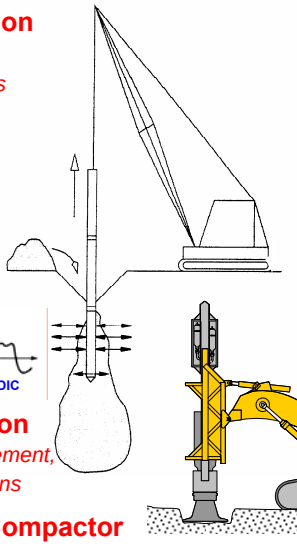




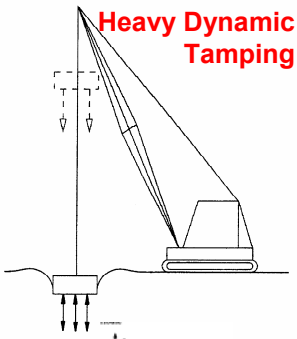
Deep vibro compaction

vibro compaction, vibro replacement, grouted stone/gravel columns

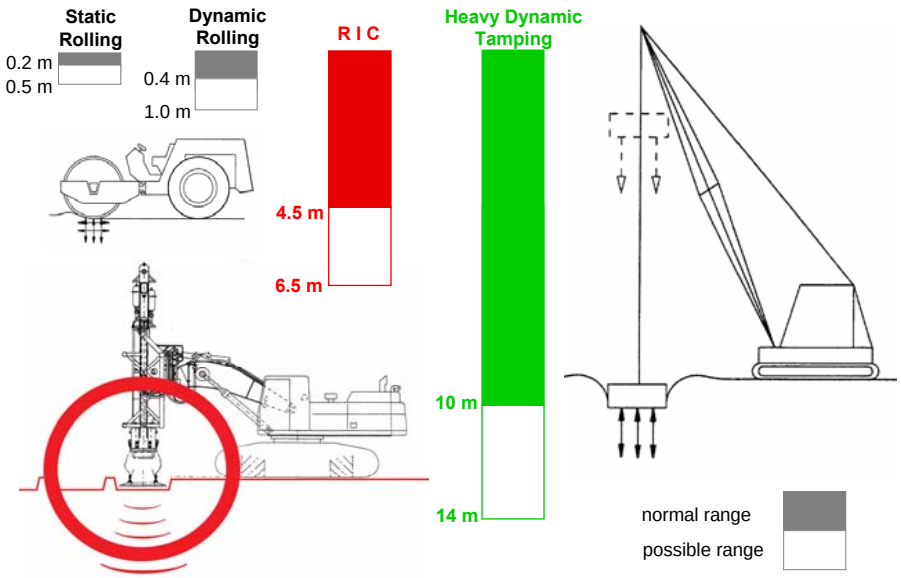
Rapid Impact Compactor



Heavy Dynamic Tamping



Compaction Depth – Comparison of Techniques




Dynamic roller compaction

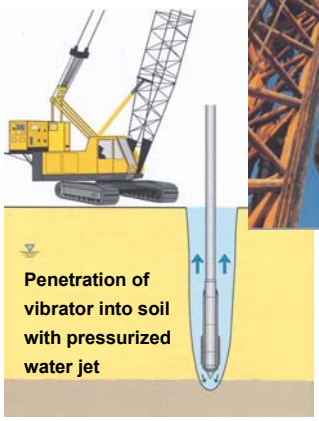

BOMAG
BOMAG
BOMAG
Continuous Compaction Control (CCC)

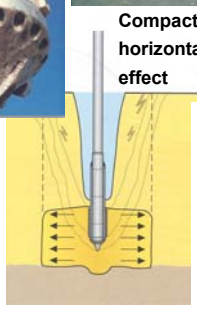

Deep Dynamic Compaction
(Heavy Tamping)

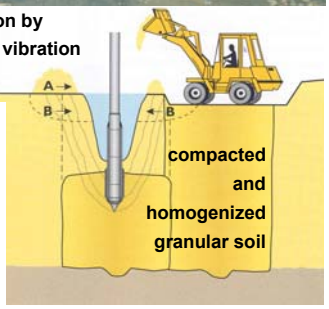

Rapid Impact Compactor (RIC)

Deep Vibro Compaction in Granular Material

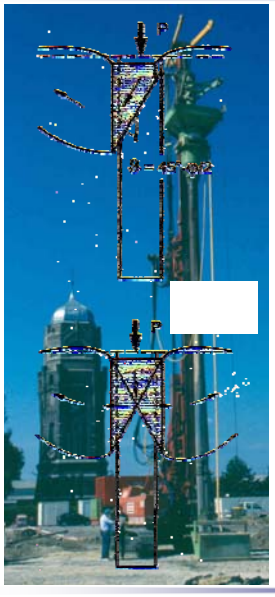
Vibro Compaction
densification and homogenization of granular soil

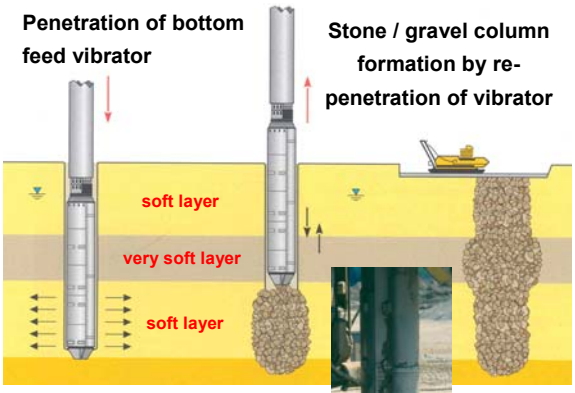






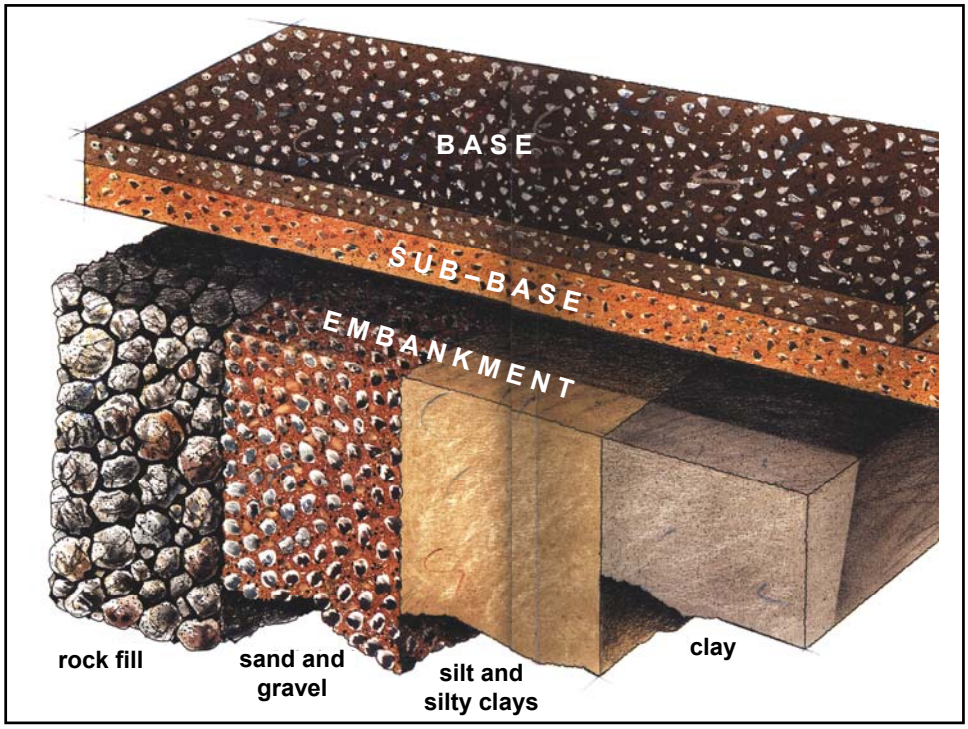
Deep Vibro Replacement of Cohesive Soils





Vibro Replacement
formation of stone / gravel columns and lateral densification of soft soil

grouted material oder **concrete**



Classification of Soil Types by Grain Size

COARSE-GRAINED / GRANULAR PARTICLES (non cohesive)

⇨ sieve analysis

200 mm
63 mm
2 mm

Boulders
Cobbles
Gravel
Sand

border line between sand and silt:
d = 0.063 mm

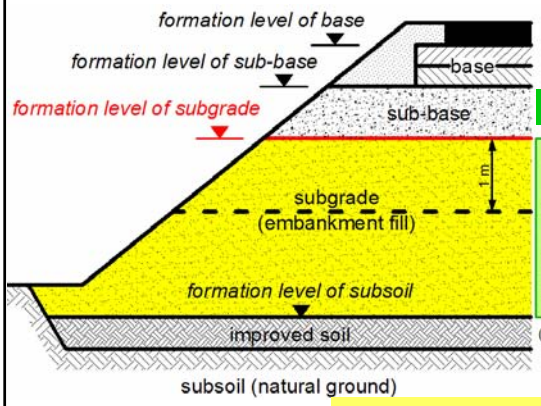
FINE-GRAINED (cohesive)

⇨ hydrometer analysis (sedimentation)

Silt
0.002 mm
Clay

GEOTECHNIK ADAM

Material for Embankments



ÖNORM B 4400

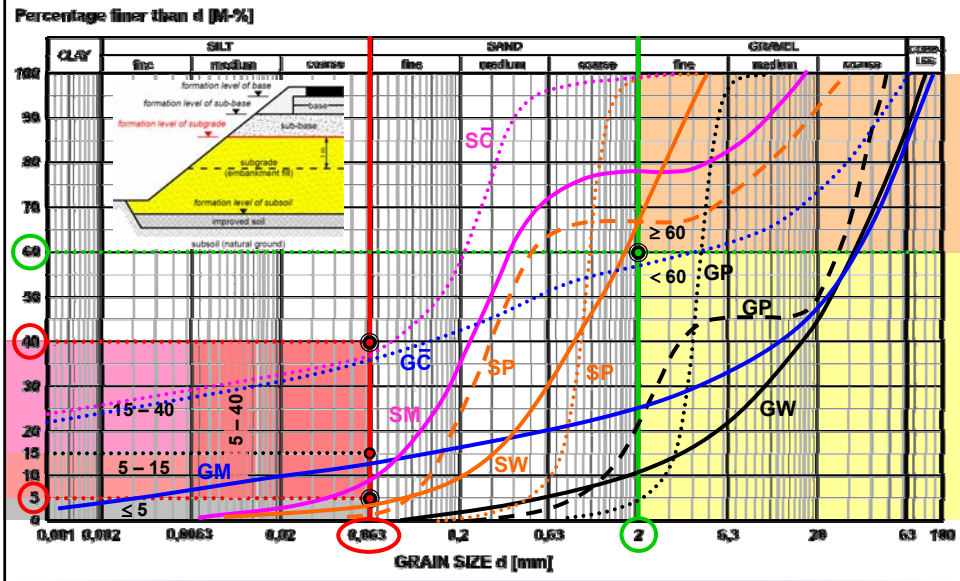
GW, GP GM, GC, SM (SW, SP) (GM, GC) (SM, SC, SC) crushed rock	GM, GC SM, SC rock well graded	mechanically stabilized poorely graded rock boulders or debris ((filter)) rock boulders or debris poorely graded	sandwich construction (recycling material) (industrial byproduct)
(suitability test)		((if necessary))	(suitability test)

„Guidelines for Recycling Materials“

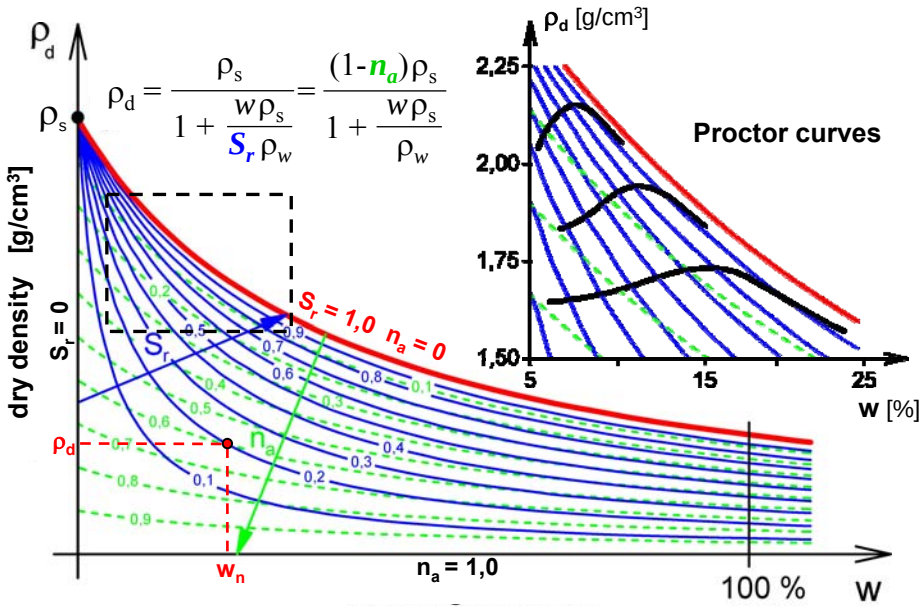
E.g.: Jet Grouting return flow = „recycled, light aggregates“
⇨ ÖNORM EN 132424, 13055-2; ÖNORM B 3137
⇨ suitability test (laboratory) + test / calibration field

For the suitability of embankment materials
the state at the time of emplacement is decisive!

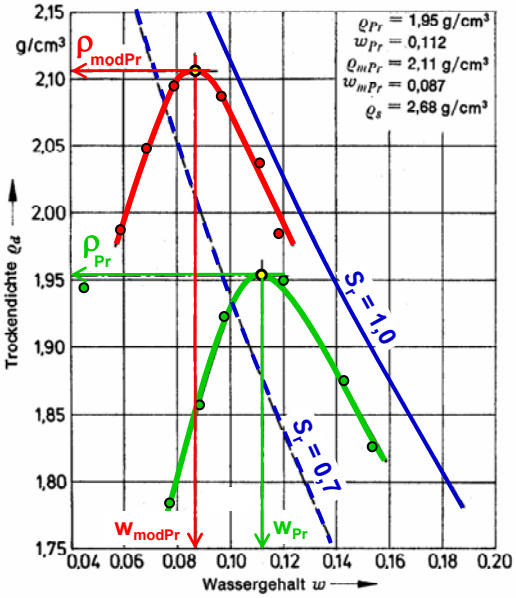
Embankment Materials



Relationship Water Content – Dry Density

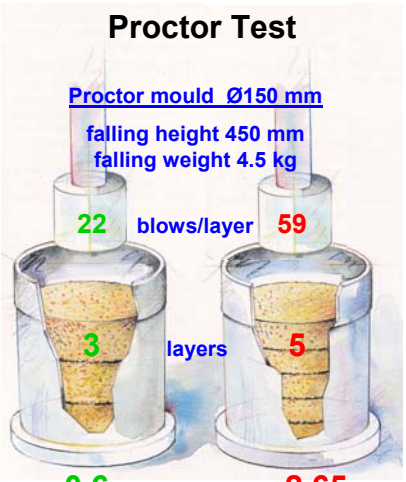


Proctor Test



Standard **Modified**

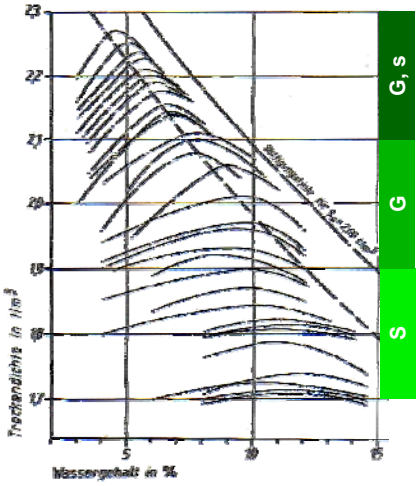
Proctor Test



0,6 energy [MJ/m³] 2,65

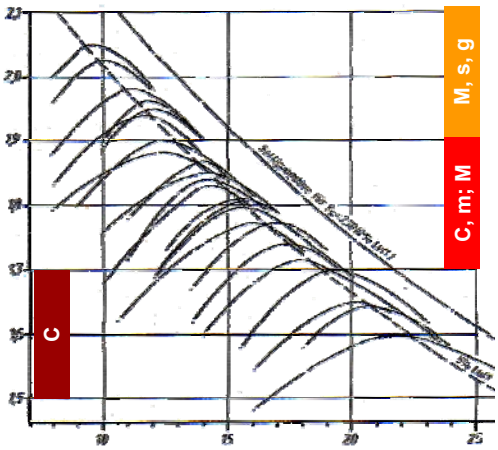
mod ρ_{Pr} = 1,03 …1,15 ρ_{Pr}

Proctor Curves of Differnet Types of Soils



COARSE GRAINED MATERIALS

FINE GRAINED MATERIALS



Compaction Control – Spot Testing Methods

DIRECT

↓

DENSITY

↓

in-situ: replacement methods (sand, water, balloon), nuclear gauge probe → ↓ → dry density ρ_d

laboratory: Proctor Test → ↓ → Standard Proctor density ρ_{Pr}

↓

COMPACTION DEGREE

$$D_{Pr} = \frac{\rho_d}{\rho_{Pr}} \; 100 \; [\%]$$

INDIRECT

↓

STIFFNESS

↓

California Bearing Ratio (CBR) | load plate test | Benkelman Beam

↓

DEFORMATION MODULUS

↓

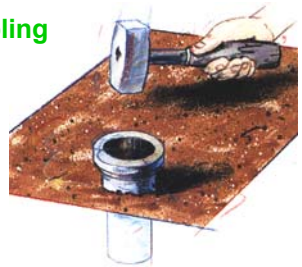
static → ↓ → E_{v1}, E_{v2}, E_{v2}/E_{v1}

dynamic → ↓ → E_{vd}

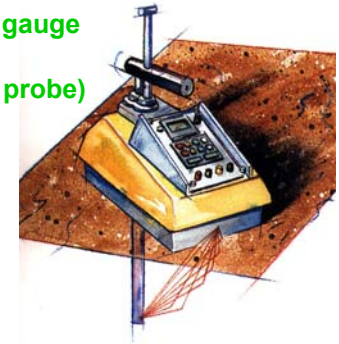
Determination of Density in Field

Sand replacement

Tube sampling



Nuclear gauge method (Troxler probe)



Compaction Control – Spot Testing Methods

DIRECT

↓

DENSITY

↓

replacement methods (sand, water, balloon), nuclear gauge probe → dry density ρ_d

Proctor Test → Standard Proctor density ρ_{Pr}

↓

COMPACTION DEGREE

$$D_{Pr} = \frac{\rho_d}{\rho_{Pr}} 100\ [\%]$$

INDIRECT

↓

STIFFNESS

↓

California Bearing Ratio (CBR) | load plate test | Benkelman Beam

↓

DEFORMATION MODULUS

↓

static → E_{v1}, E_{v2}, E_{v2}/E_{v1}

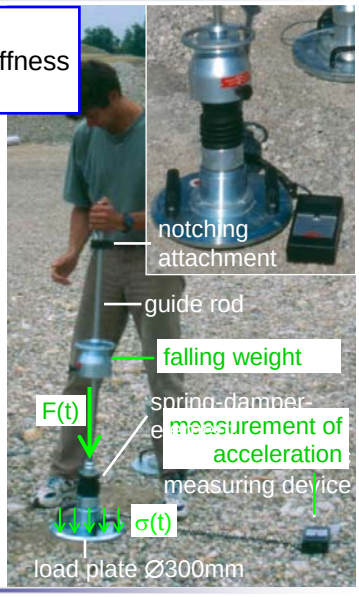
dynamic → E_{vd}

Compaction Control Methods using Load Plate Tests

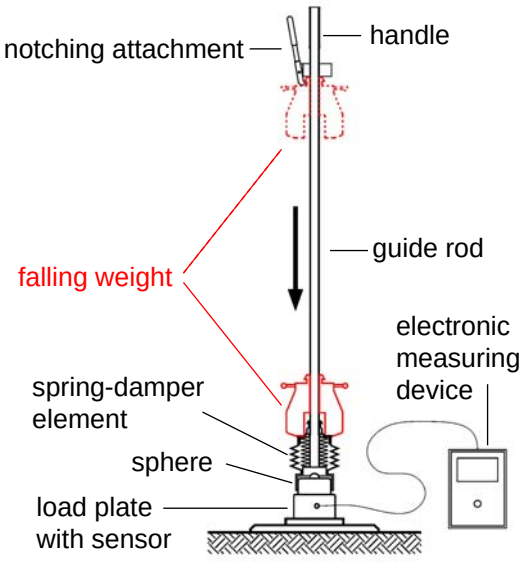
- determination of **deformation modulus**
- checking of compaction quality and material stiffness
- for earth works and road construction

Static load plate test

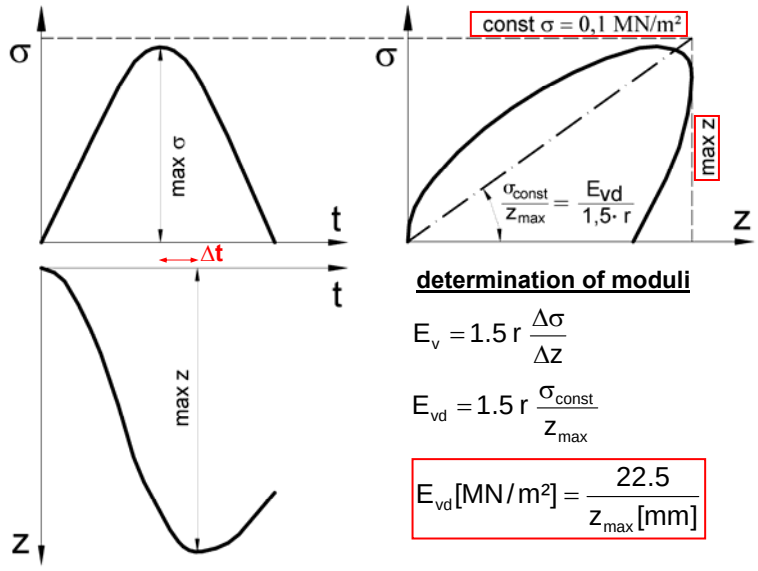
Dynamic load plate test with the **L**ight **F**alling **W**eight **D**evice



Dynamic Load Plate – „Light Falling Weight Device“



Standardized Test Evaluation



determination of moduli

$$E_v = 1.5\, r\, \frac{\Delta\sigma}{\Delta z}$$

$$E_{vd} = 1.5\, r\, \frac{\sigma_{const}}{z_{max}}$$

$$E_{vd}[MN/m^2] = \frac{22.5}{z_{max}[mm]}$$

Research Results ⇨ Standardization RVS 08.03.04

Requirements on the device:

\+ → tuning of the device parameters

\+ set of disc springs made of steel – synthetic spring (!)

\+ → exactly defined requirements on the deflection measuring device

\+ → calibration at least once a year

Standardized test execution and test evaluation:

\+ → measuring range **E_{vd} = 7,5 - 90 MN/m²**

\+ → **3** pre-loading impacts and **3** measuring impacts

\+ → assumption of a constant maximum ground contact force (max F)

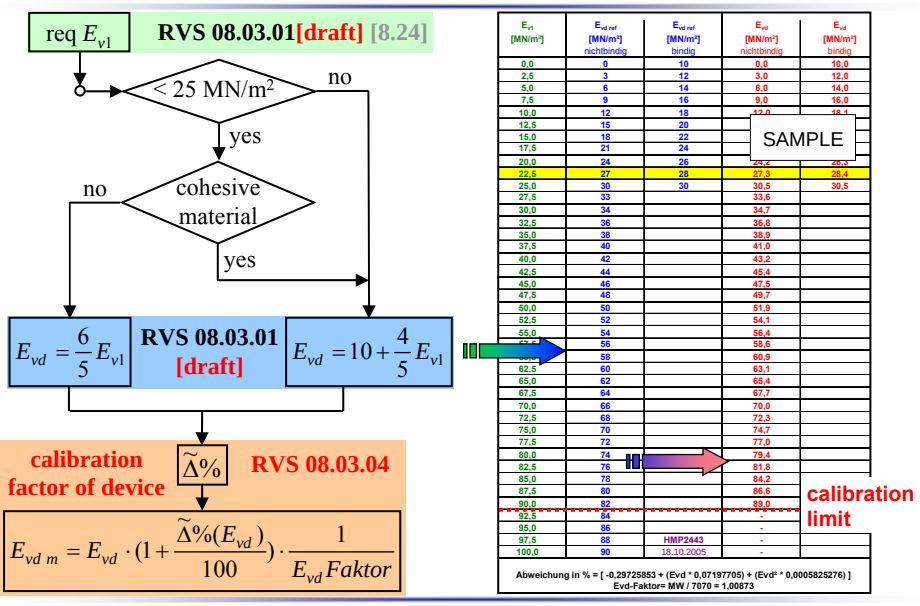
\+ → simplified determination of the dynamic deformation modulus (E_{vd})

\+ → measuring depth (2 x plate diameter), lateral angle of influence (40°)

~ → ratio “s/v” as criterion for the compaction quality

– → direct correlation with values obtained by static load plate tests

Check of the required E_{v1} with the LFWD



Selection of Compaction Control Method (RVS 08.03.01[draft])

Standards

1. **Dynamic Load Plate Test (LFWD) ⇨ E_{vd}** — **RVS 08.03.04**

   or

2. **Static Load Plate Test ⇨ E_{v1}** — **ÖNORM B 4417**

   or

3. **Compaction degree D_{Pr}:** — **ÖNORM B 4414-2**, **DIN 18125-2**, **Bulletin FGSV**, **ÖNORM B 4418**

   determination of Proctor density ρ_{Pr}

   \+ determination of density in field ρ_d

   3.1 sand replacement

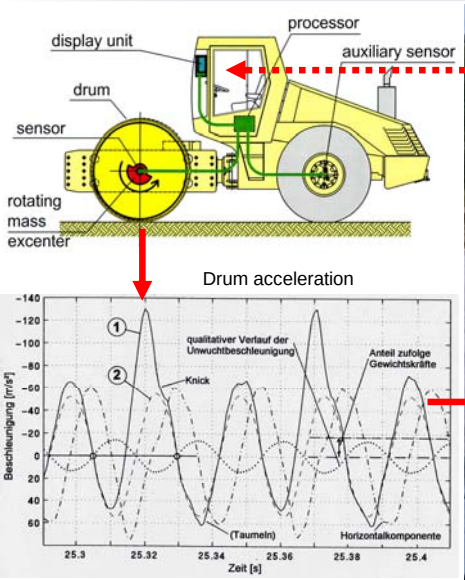
   3.2 water replacement

   3.3 nuclear gauge probe

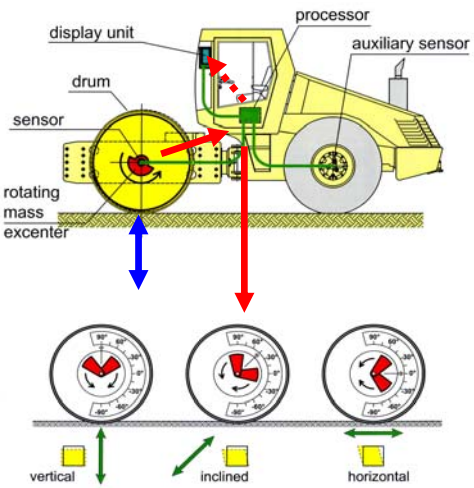
other control methods: — **when area of subgrade level ≥ 30,000 m²** — **Bulletin FGSV**, **ÖNORM B 4405 + B 4419**

- Benkelman Beam
- dynamic penetration tests (e.g. DPH)
- levelling

Continuous Compaction Control (CCC)

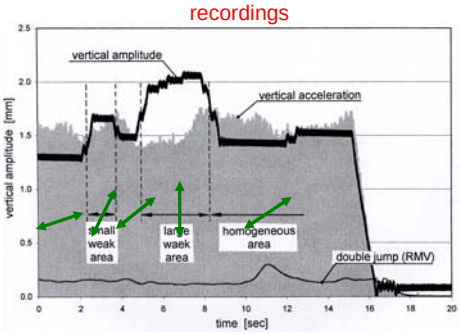


Automatically Controlled Compaction

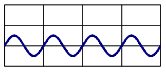
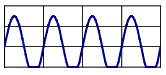
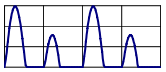
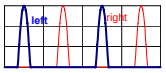
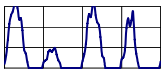


automatic inclination of exciter unit

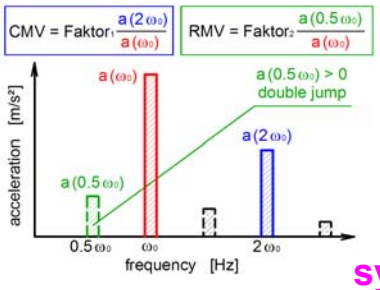
recordings



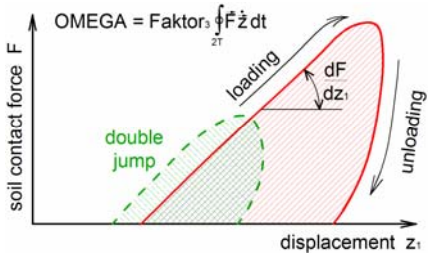
Operating Modes of Vibratory Roller Drums

drum motion	Interaction drum-soil	operating condition	soil contact force	application of CCC	soil stiffness	roller speed	drum ampli-tude
periodic	continuous contact	CONT. CONTACT		yes	low	fast	small
	periodic loss of contact	PARTIAL UPLIFT		yes			
		DOUBLE JUMP		yes			
		ROCKING MOTION		no			
chaotic	non-periodic loss of contact	CHAOTIC MOTION		no	high	slow	large

Compactometer – ***CMV*** is based on the evaluation of the acceleration in the *frequency domain*

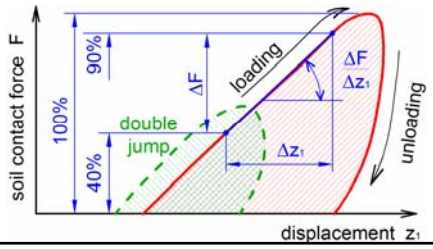


Terrameter – ***OMEGA*** is based on the evaluation of the energy transmitted to the soil in the *time domain*

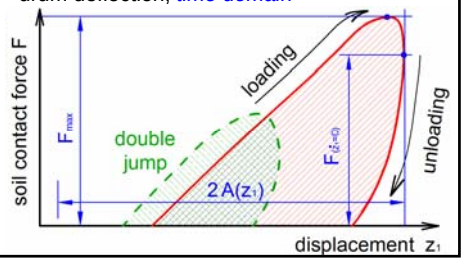


CCC-systems

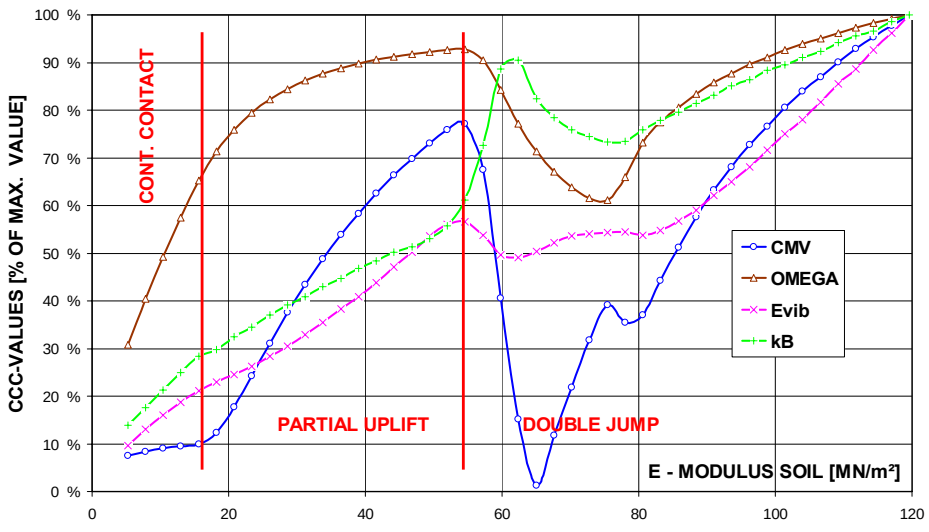
Terrameter – ***E_{VIB}*** ⇨ inclination of the soil contact force displacement relationship during loading; *time domain*



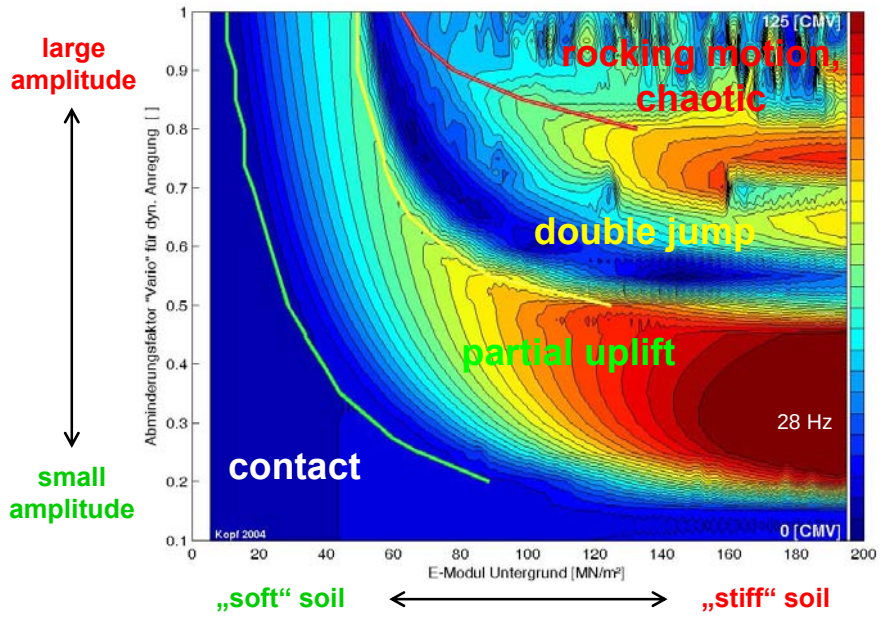
ACE – ***k_B*** ⇨ derived from the soil contact force displacement relationship at maximum drum deflection; *time domain*



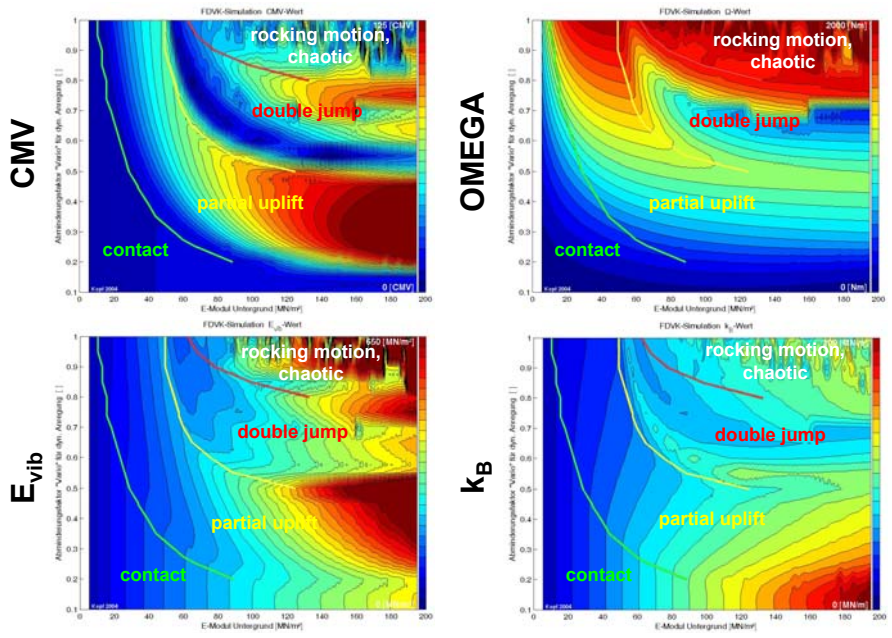
CCC-values – CMV, OMEGA, E_{vib}, k_B



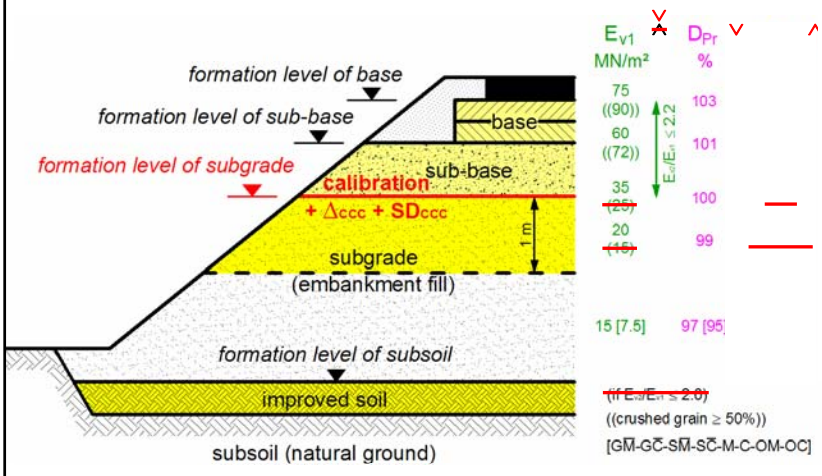
CMV in Dependence of the Operating Conditions



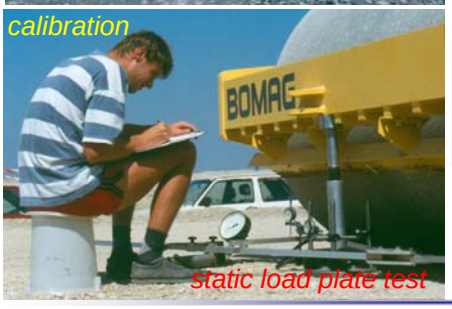
Comparison of Different CCC-Values

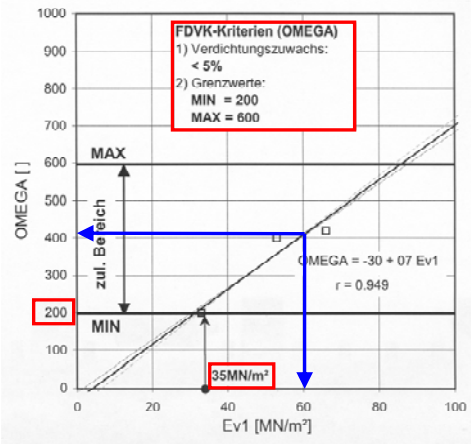


Earth Work ⇨ RVS 08.03.01[draft] [8.24]



Continuous Compaction Control (CCC)



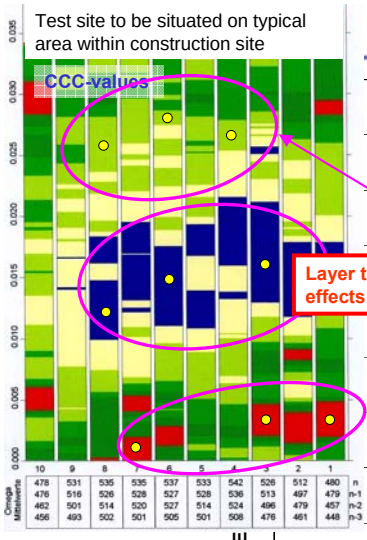


Calibration of CCC-values

Determination of a clear correlation between soil stiffness and CCC-values

Calibration of CCC-values

Test site to be situated on typical area within construction site



Static load plate 9 tests
Dynamic load plate 36 tests (4 x 9)

Layer thickness and different depth effects have to be taken into account!

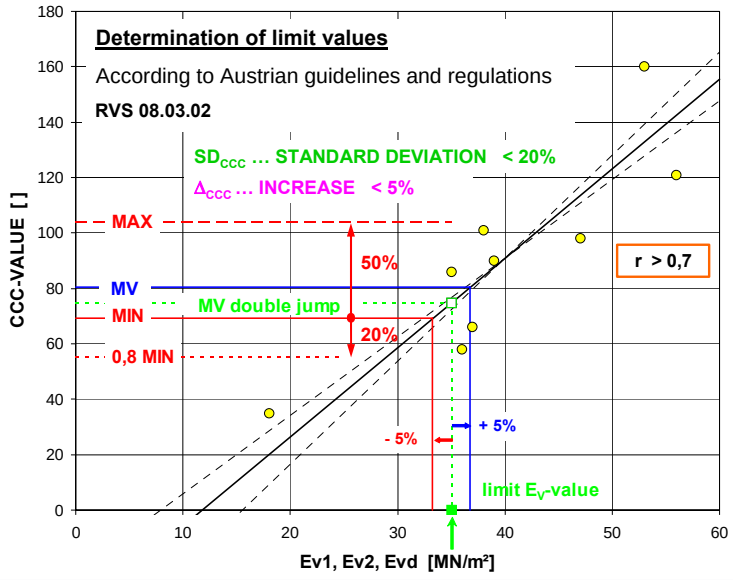
high values
mean values
low values

r > 0,7

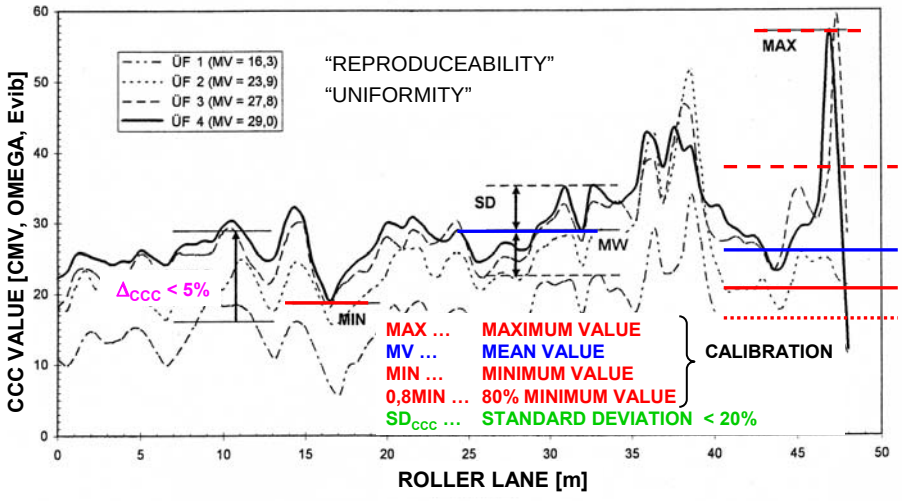
Determination of regression line

CCC-VALUE
Ev1, Ev2, Evd [MN/m²]

Calibration of CCC-values



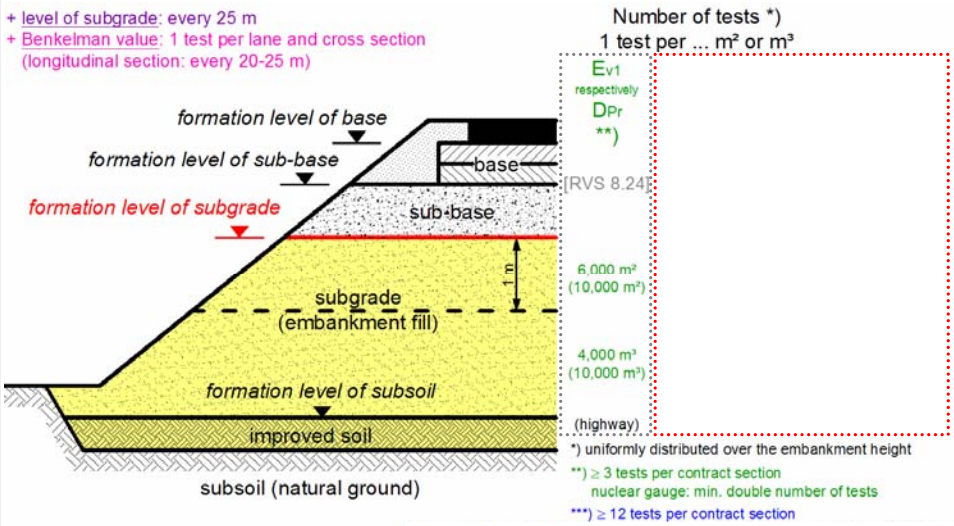
Continuous Compaction Control (CCC)



Acceptance Test („Identitäts-[Abnahme-]Prüfung“)

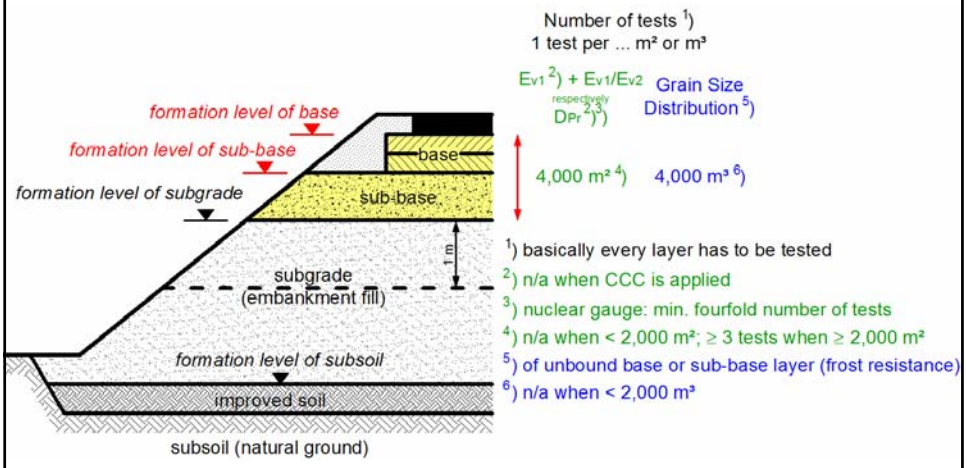
subgrade (RVS 08.03.01[draft] [8.24])

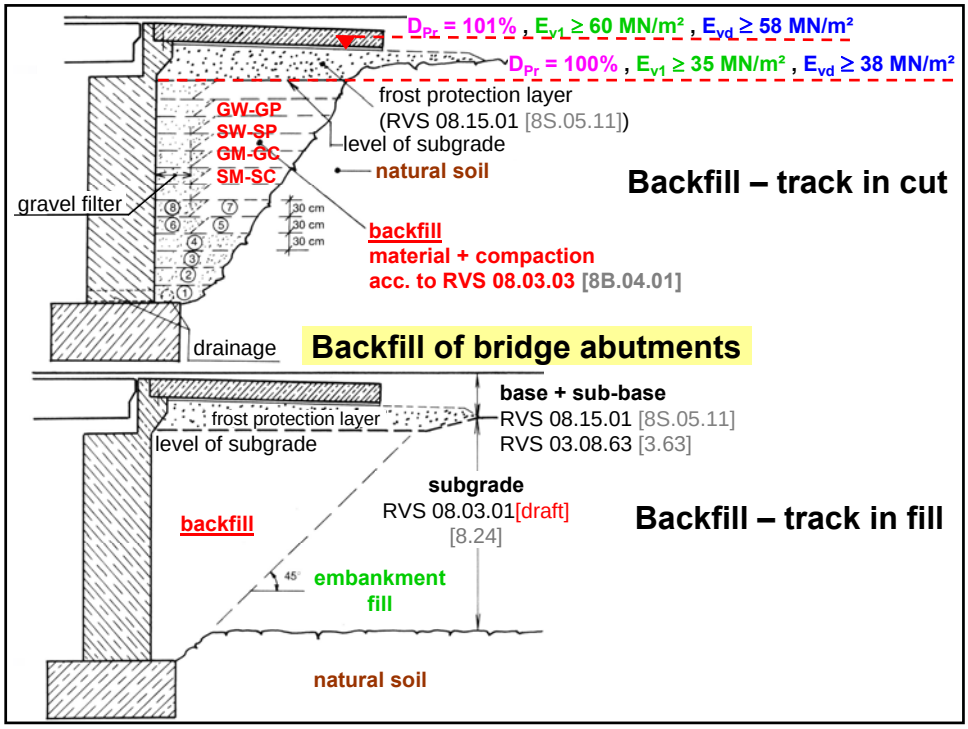
+ level of subgrade: every 25 m
+ Benkelman value: 1 test per lane and cross section (longitudinal section: every 20-25 m)

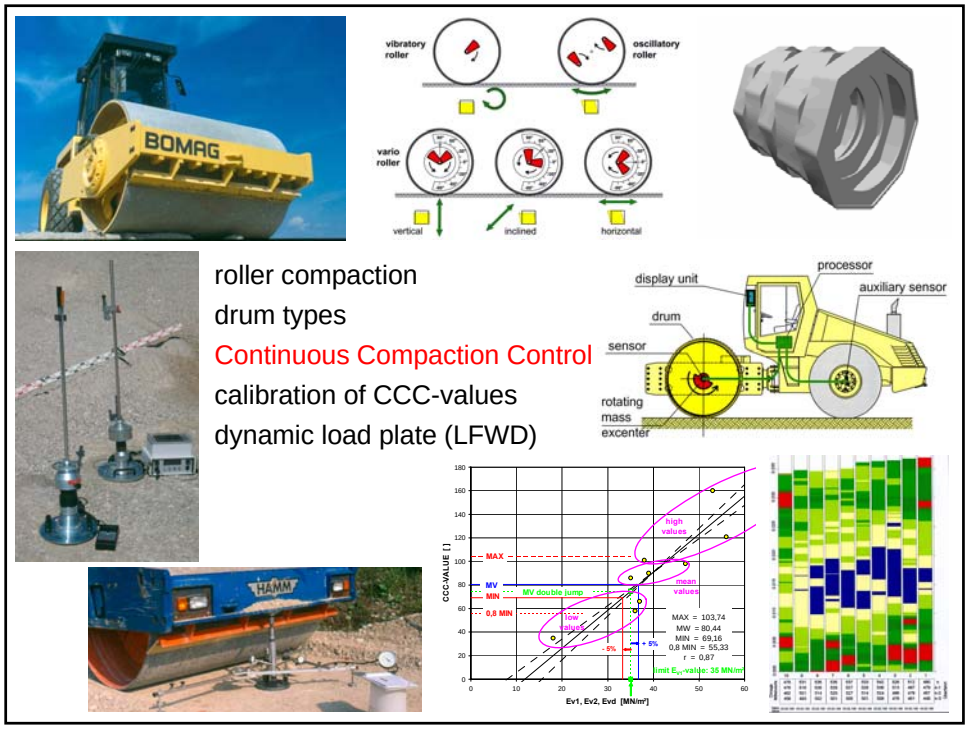


Acceptance Test („Identitäts-[Abnahme-]Prüfung“)

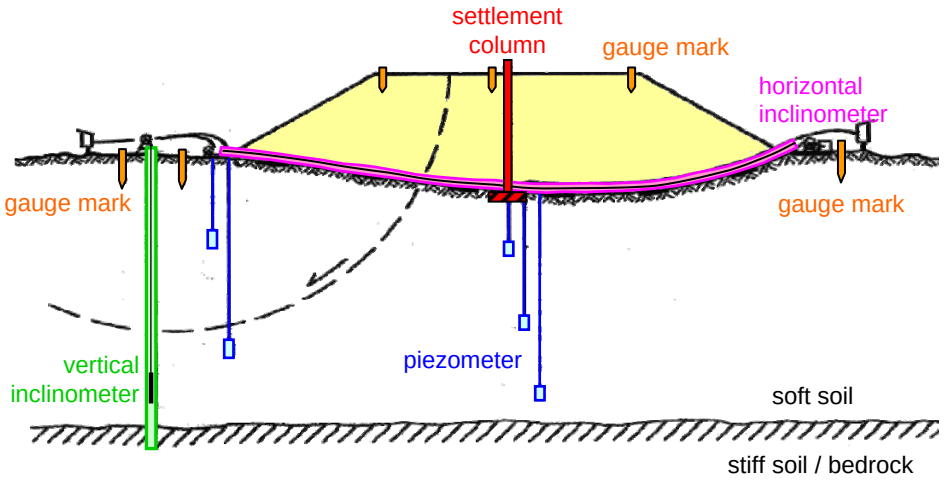
base and sub-base (RVS 08.15.01 [8S.05.11])



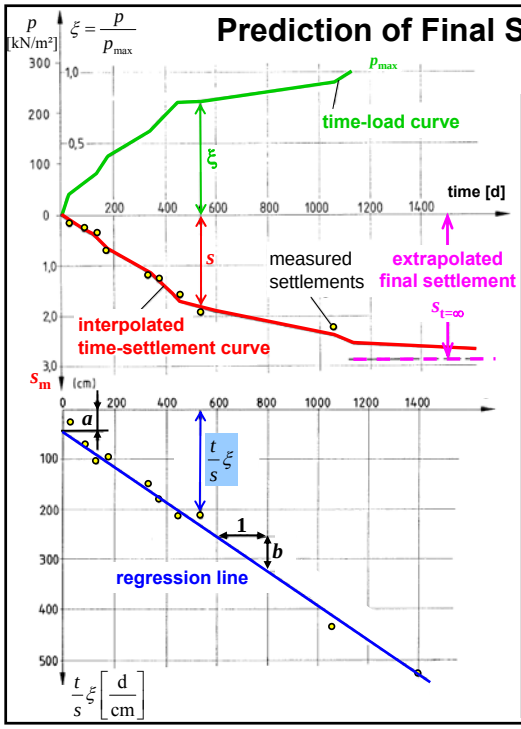

D_{Pr} = 101% , $E_{v1} \geq 60$ MN/m² , $E_{vd} \geq 58$ MN/m²
D_{Pr} = 100% , $E_{v1} \geq 35$ MN/m² , $E_{vd} \geq 38$ MN/m²
frost protection layer
(RVS 08.15.01 [8S.05.11])
level of subgrade
natural soil
GW-GP
SW-SP
GM-GC
SM-SC
gravel filter
30 cm
30 cm
30 cm
backfill
material + compaction
acc. to RVS 08.03.03 [8B.04.01]
drainage
Backfill – track in cut
Backfill of bridge abutments
frost protection layer
level of subgrade
base + sub-base
RVS 08.15.01 [8S.05.11]
RVS 03.08.63 [3.63]
subgrade
RVS 08.03.01[draft]
[8.24]
backfill
45°
embankment
fill
natural soil
Backfill – track in fill


BOMAG
vibratory roller
oscillatory roller
vario roller
vertical
inclined
horizontal
roller compaction
drum types
Continuous Compaction Control
calibration of CCC-values
dynamic load plate (LFWD)
display unit
processor
auxiliary sensor
drum
sensor
rotating mass excenter
HAMM
CCC-VALUE [ ]
Ev1, Ev2, Evd [MN/m²]
MAX
MV
MIN
0,8 MIN
MV double jump
high values
mean values
low values
+ 5%
- 5%
MAX = 103,74
MW = 80,44
MIN = 69,16
0,8 MIN = 55,33
r = 0,87
limit E_{v1}-value: 35 MN/m²

Embankment on Soft Soil – Measurement of Deformations



Prediction of Final Settlement – Sherif (1973)



ÖNORM B 4431-2

- measurement of settlements s
- documentation of load history p
- assumption: **hyperbolic function** for settlement curve

$$s(t) = \frac{t}{a + b\,t}\xi$$

- **dimensionless parameter ξ**

$$\xi = \frac{p}{p_{max}}$$

⇨ adaption of settlement curve to the load history

- **transformation**:

$$s \rightarrow \frac{t}{s}\xi$$

- **regression line**: a + b.t
- **extrapolation**: $s_{t=\infty} = 1/b$

Monitoring of Slope Deformations

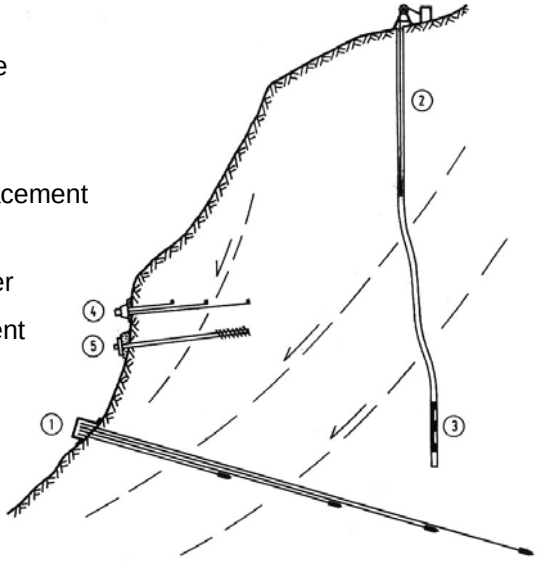
① extensometer in borehole

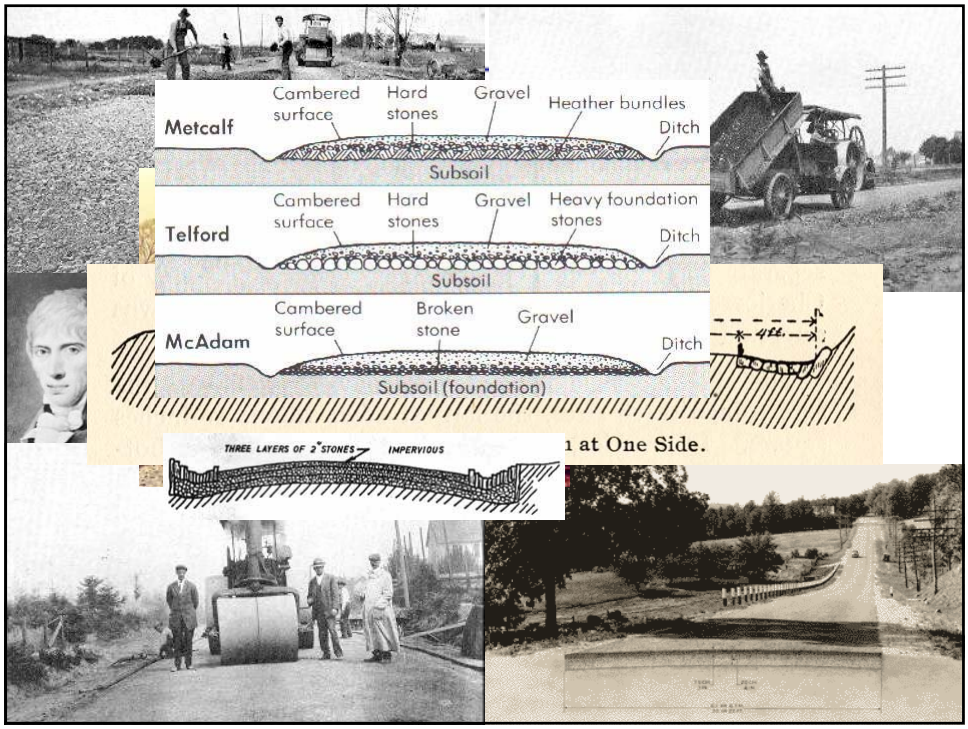
② inclinometer gauge
- lateral inclination
- axial incremental displacement

③ deflectometer

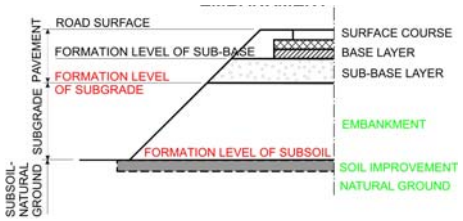
④ multiple rod extensometer

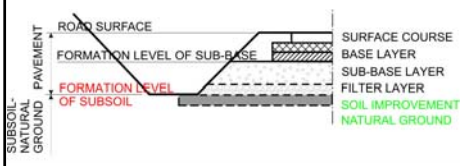
⑤ anchor force measurement




Metcalf
Cambered surface
Hard stones
Gravel
Heather bundles
Ditch
Subsoil
Telford
Cambered surface
Hard stones
Gravel
Heavy foundation stones
Ditch
Subsoil
McAdam
Cambered surface
Broken stone
Gravel
Ditch
Subsoil (foundation)
THREE LAYERS OF 2" STONES
IMPERVIOUS
at One Side.

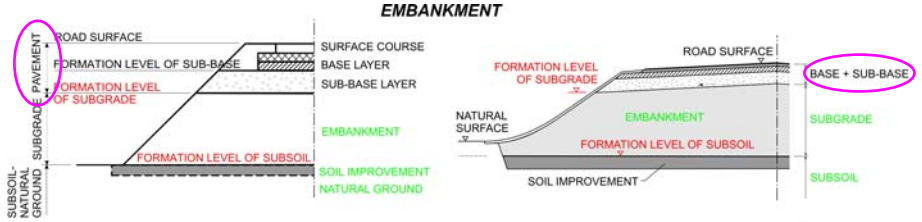
RVS 8.24



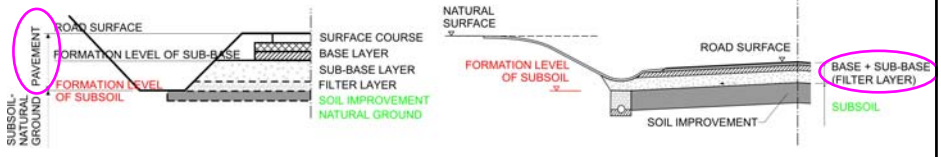


RVS 8.24 ⇨ RVS 08.03.01

EMBANKMENT



CUT !!! ***TRENCH***



Methods of Ground Improvement

Ground REPLACEMENT	soil excavation and soil exchange	
Ground COMPACTION	surface-near compaction, deep vibro compaction, heavy dynamic tamping, Rapid Impact Compaction	**MECHANICAL Ground Improvement**
Ground CEMENTATION	soil stabilization with cement and lime, grouting, jet grouting, soil freezing	
Ground DRAINAGE	vertical drains, vacuum consolidation, surcharging and preloading	
Ground REINFORCEMENT	reinforcement, cell structures	

Technical Testing Standard TP BF - StB part B 8.3

Dynamic load plate test with the Light Falling Weight Device (LFWD)

1. Application range E_{vd} = 15 - 80 MN/m²

   Testing of bearing capacity and compaction quality of soils and unbound base layers in earth works and construction of traffic systems

2. Terms
3. Devices → dimensions, masses, measurement data acquisition, tolerances
4. Testing conditions → soil characteristics and inclination of testing surface
5. Test execution → **3** pre-loading impacts + **3** measuring impacts
6. Test report and evaluation
7. Calibration of the device → carried out by a certified institute (at least once a year)

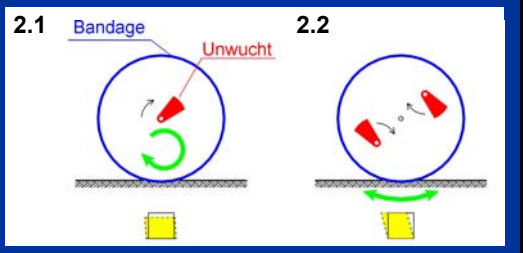
→ loading device *adjustment of falling height + possibly spring prestressing*

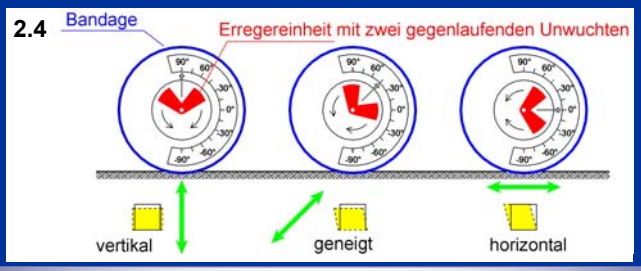
→ displacement measuring device

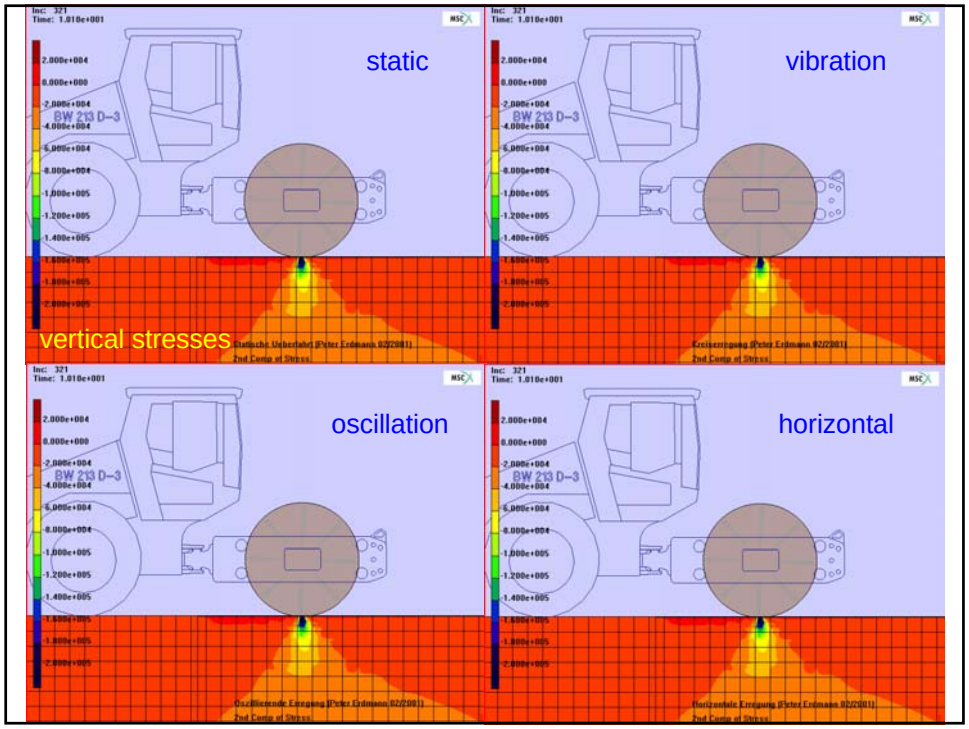
Oberflächenverdichtung mit Walzen

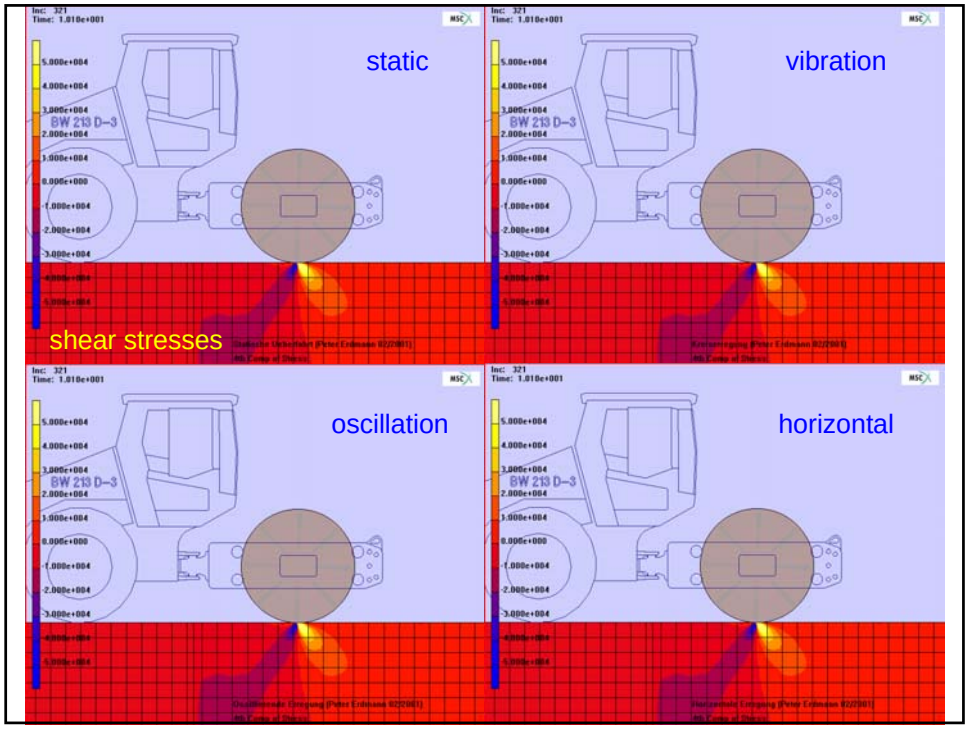
1. **statische** Walzen

2. **dynamische** Walzen
   - 2.1 Vibrationswalze
   - 2.2 Oszillationswalze
   - 2.3 Walze mit Richtschwinger
   - 2.4 automatisch geregelte Walzen (VARIOCONTROL, VARIOMATIC, ACE)

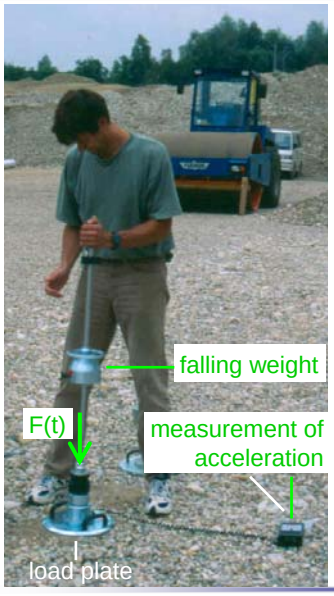




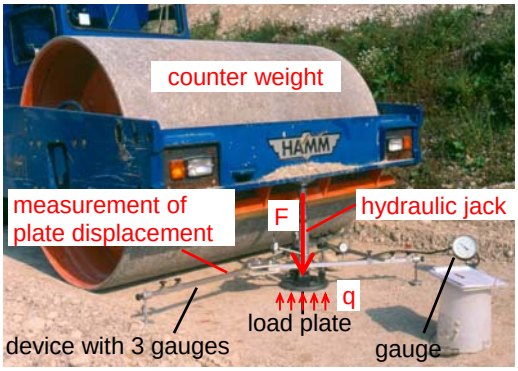




Compaction Control Methods using Load Plate Tests



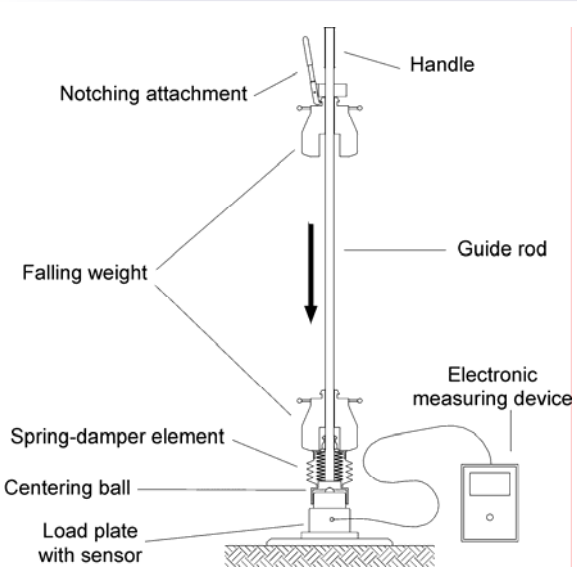
- determination of deformation modulus
- checking of compaction quality and bearing capacity
- for earth works and road construction



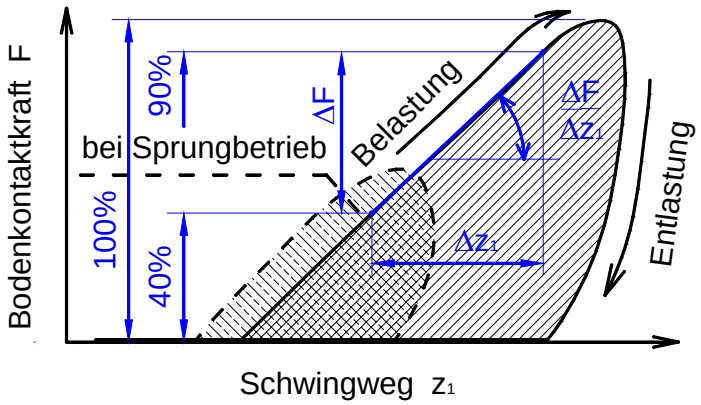
static load plate test

dynamic load plate test

Dynamic Load Plate – „Light Falling Weight Device“

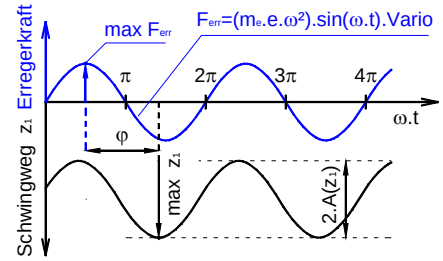


CCC-value E_{vib} ⇨ time domain



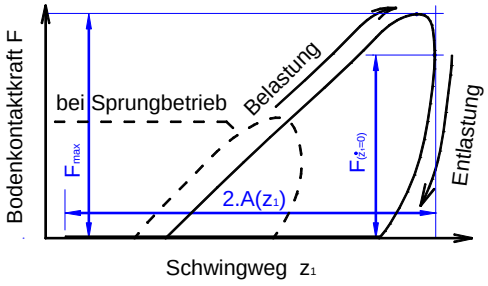
$$\frac{\Delta F}{\Delta z_1} = \frac{E_{vib} \cdot 2 \cdot a \cdot \pi}{2 \cdot (1-\nu^2) \cdot \left(2{,}14 + 0{,}5 \cdot \ln\left(\frac{\pi \cdot (2 \cdot a)^3 \cdot E_{vib}}{(1-\nu^2) \cdot 16 \cdot (m_b + m_e + m_r) \cdot g \cdot (d/2)} \right) \right)}$$

CCC-value k_B ⇨ time domain



contact

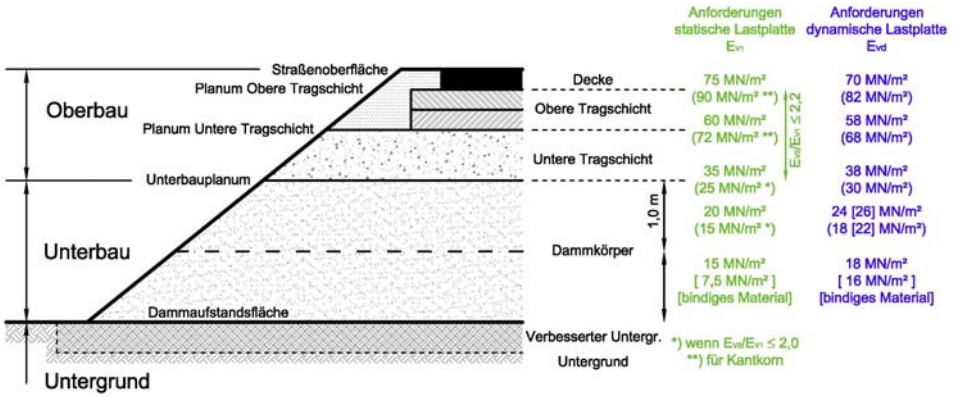
$$k_B = \omega^2 \cdot \left((m_b + m_e) + \frac{(m_e \cdot e \cdot Vario) \cdot \cos(\varphi)}{A_{(z_1)}} \right)$$



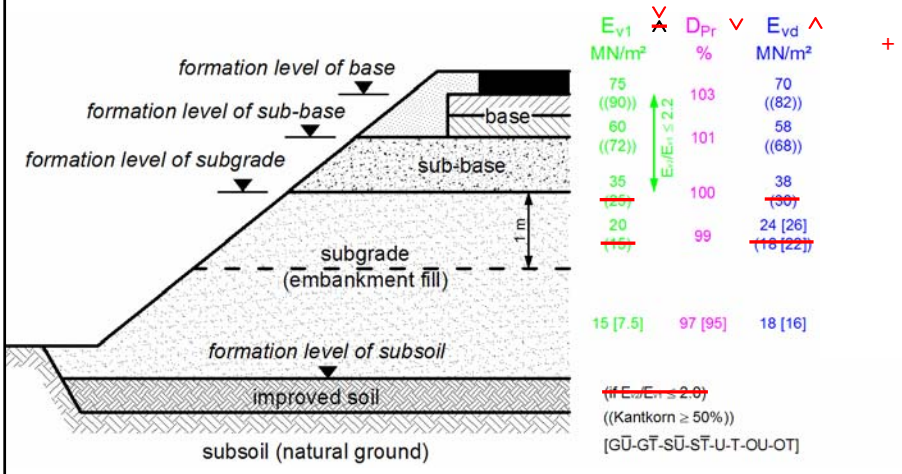
loss of contact

$$k_B = \frac{F_{(\dot{z}_1=0)} - (m_b + m_e + m_r) \cdot g}{A_{(z_1)}}$$

Earth Work ⇨ RVS 08.03.01 (RVS 8.24) … revision



Earth Work ⇨ RVS 08.03.01[draft] [8.24]



Acceptance Test („Identitäts- [Abnahme-] Prüfung“)