MAÚT Mérnökakadémia
Útépítés és geotechnika – szabályok és tapasztalatok
MAKADÁM-Klub
Budapest, Lövőház u. 15.
16. január 2008

# *Földművek tervezése, minőségbiztosítása és monitoringja Ausztriában*

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


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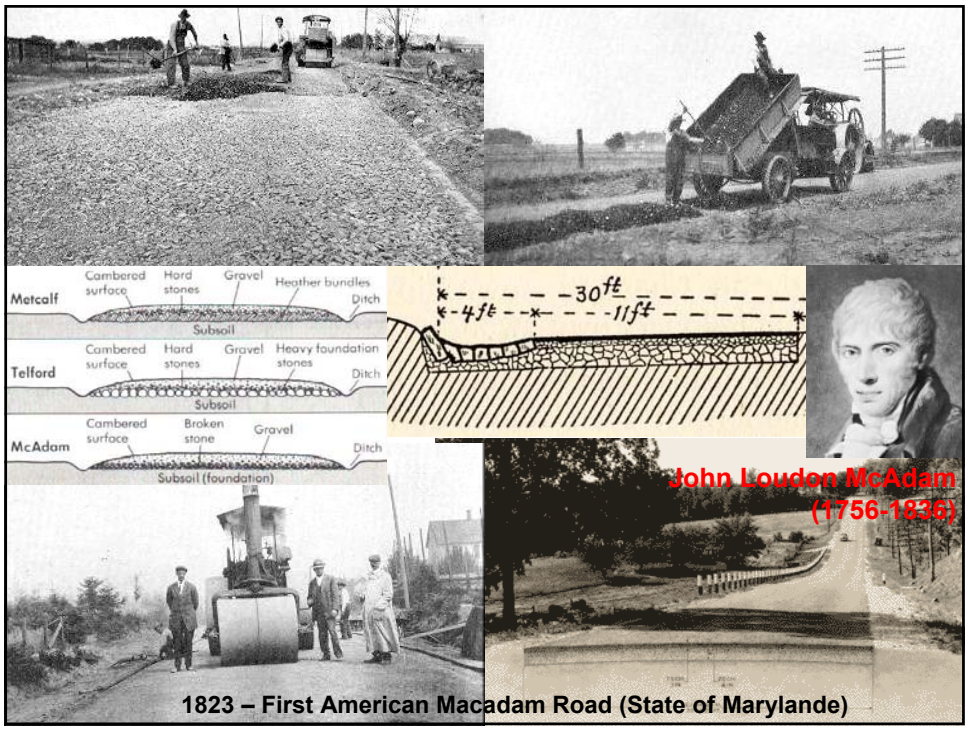
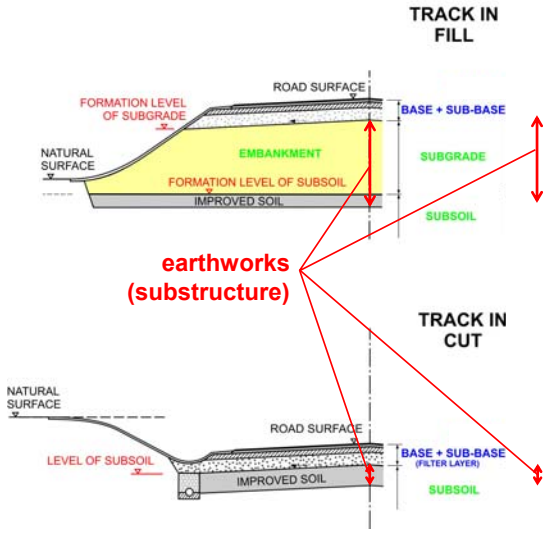



**1823 – First American Macadam Road (State of Marylande)**

[RVS 8.24] ⇨ RVS 08.03.01 [draft]

„Earthworks“ „Earthworks under Traffic Routes“

ROAD

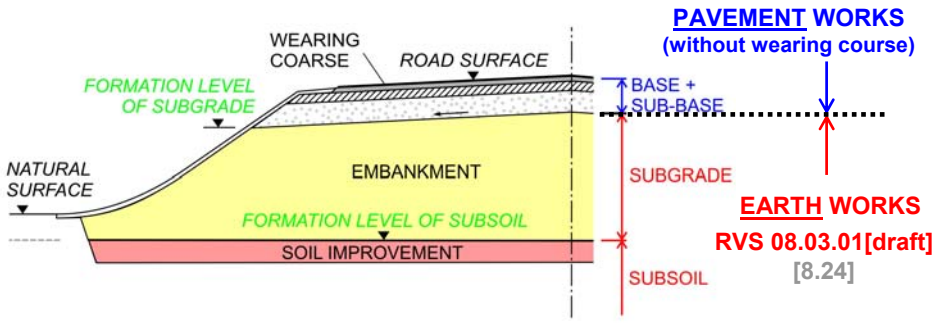



## Cross Section – Definitions and Standards

**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

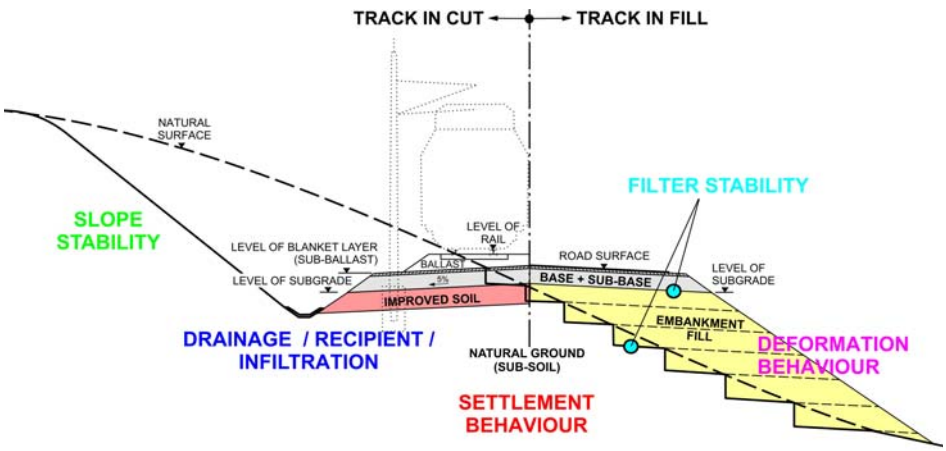



ÖNORM B 4417: static load plate test

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

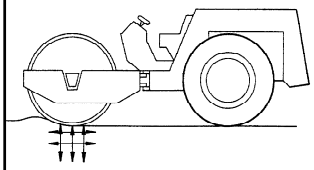
| | | |
|---|---|---|
| 1 | **Ground COMPACTION** | surface-near compaction |
| 2 | **Ground REPLACEMENT** | soil excavation and soil exchange |
| 3 | **MECHANICAL Improvement** | Mixing in suitable granular material to improve poorly graded materials (SP, GP), fine materials (silty or clayey) or soft 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<br>▪ vertical drains<br>▪ deep vibro compaction<br>▪ deep dynamic compaction (heavy tamping)<br>▪ pile foundation |

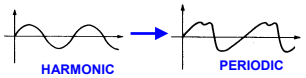
# Surface-near and Deep Ground Improvement

**surface-near**

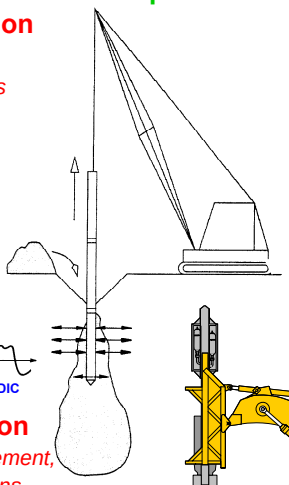
**Dynamic roller compaction**

*vibratory, oscillatory, VARIO, automatically controlled rollers*





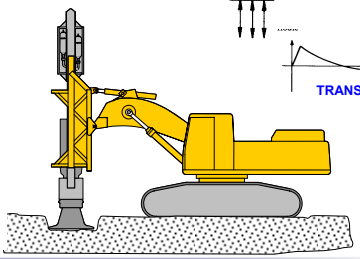

**deep**



**Deep vibro compaction**

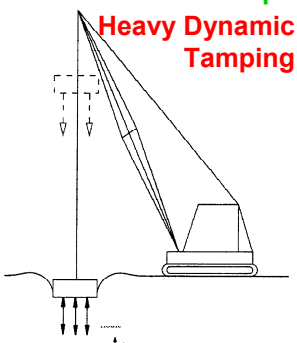
*vibro compaction, vibro replacement, grouted stone/gravel columns*

**Rapid Impact Compactor**



**surface-near & deep**

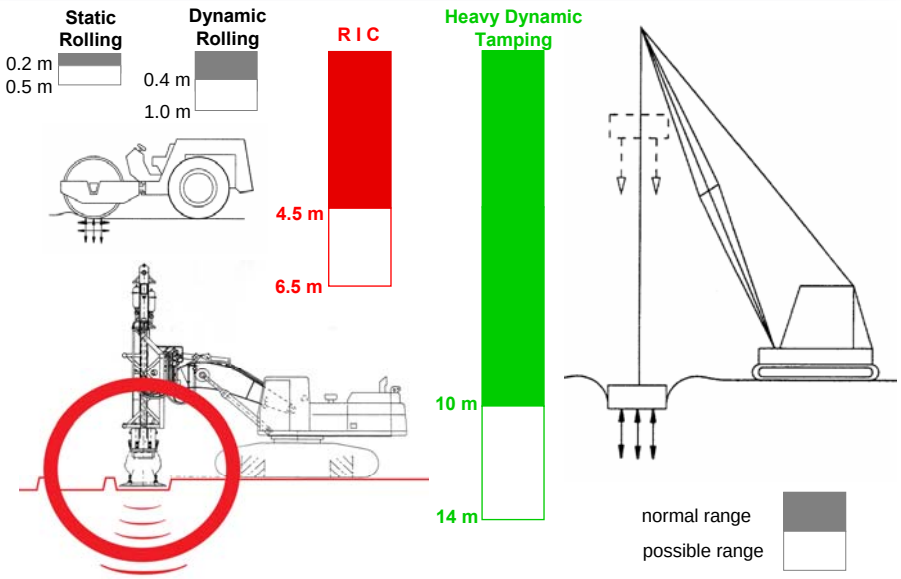
**Heavy Dynamic Tamping**








# Compaction Depth – Comparison of Techniques




Dynamic roller compaction

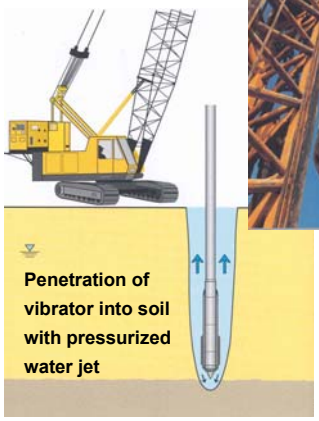

BOMAG
BOMAG
BOMAG
Continuous Compaction Control (CCC)

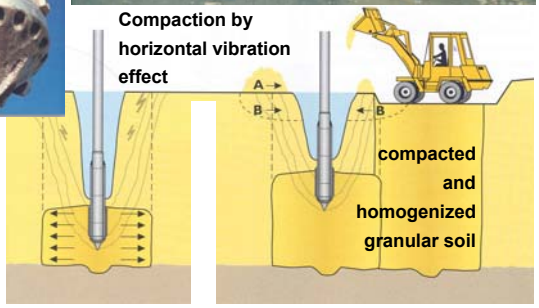

Deep Dynamic Compaction
(Heavy Tamping)


Rapid Impact Compactor (RIC)

# Deep Vibro Compaction in Granular Material

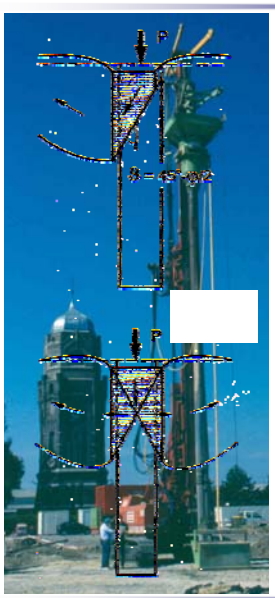
**Vibro Compaction**
densification and homogenization of granular soil

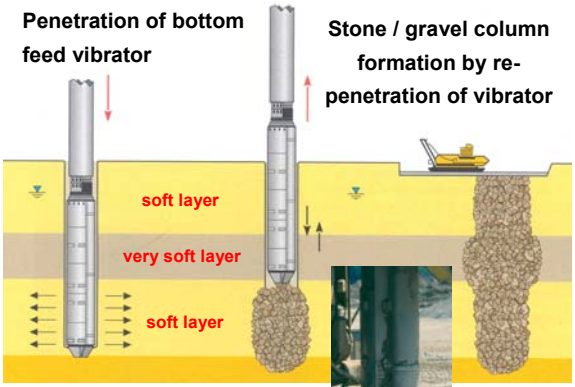



# Deep Vibro Replacement of Cohesive Soils



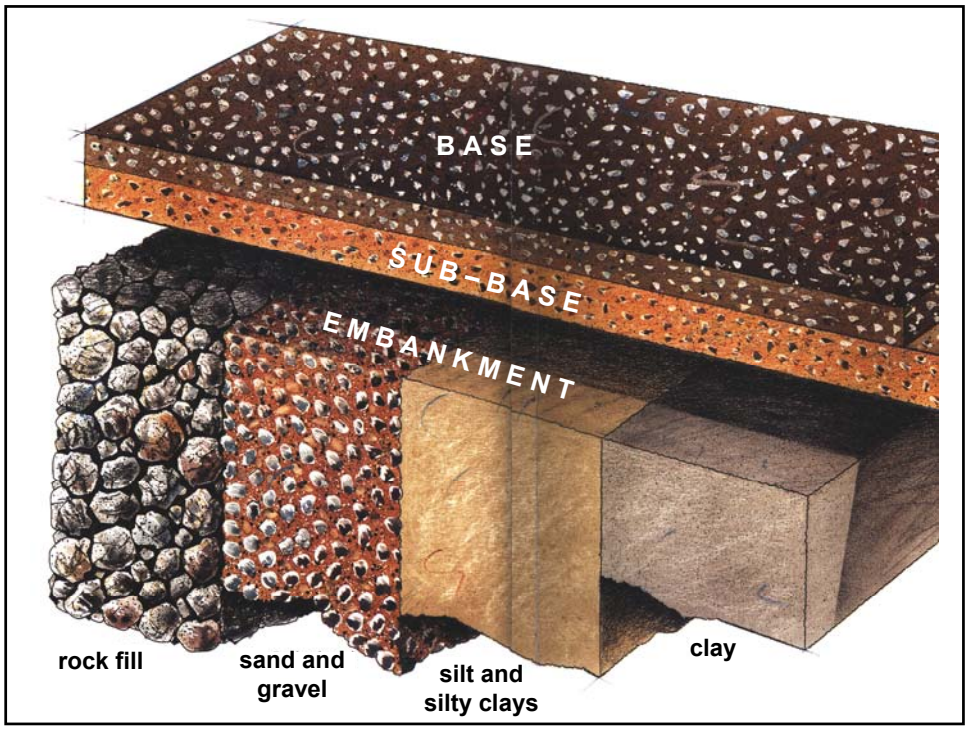
Penetration of bottom feed vibrator

Stone / gravel column formation by re-penetration of vibrator




**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)

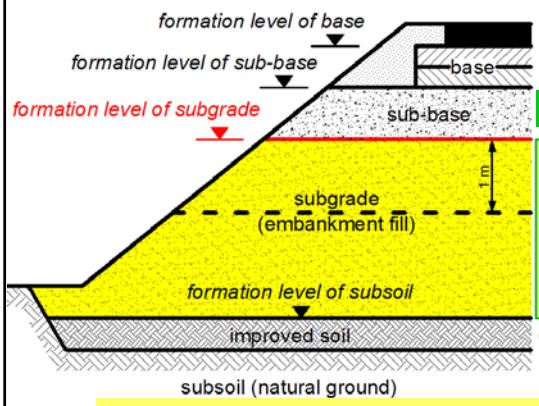
Silt

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“**

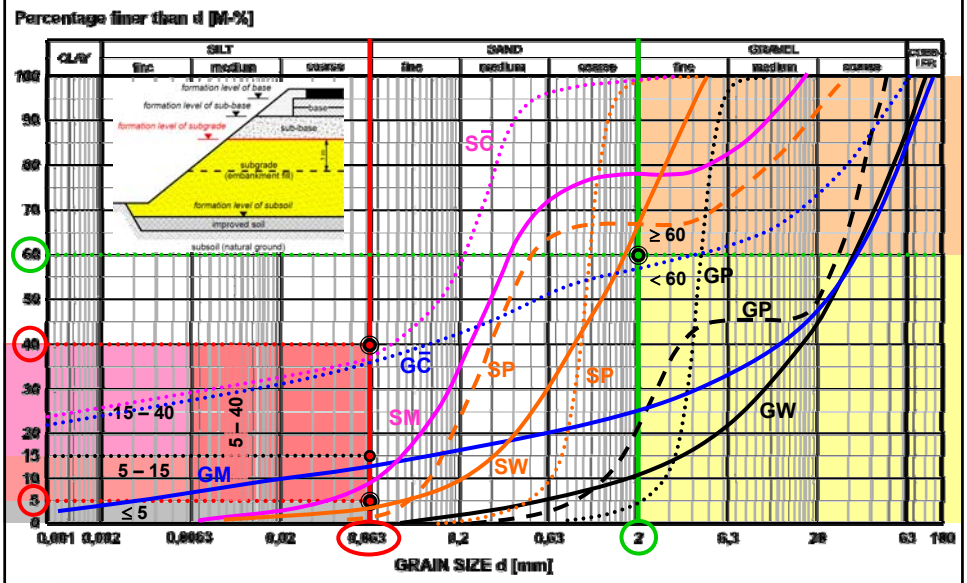
**Standards: ÖNORM EN 132424, 13055-2; ÖNORM B 3137**

**Quality assurance: suitability test (laboratory) + test site / calibration field**

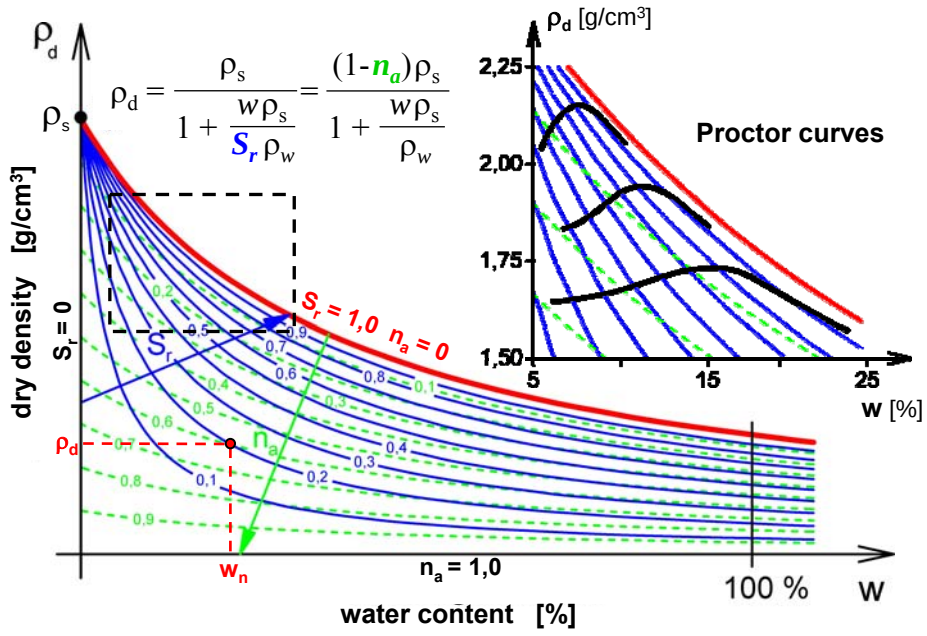
***For the suitability of embankment materials***
***the state at the time of emplacement is decisive!***



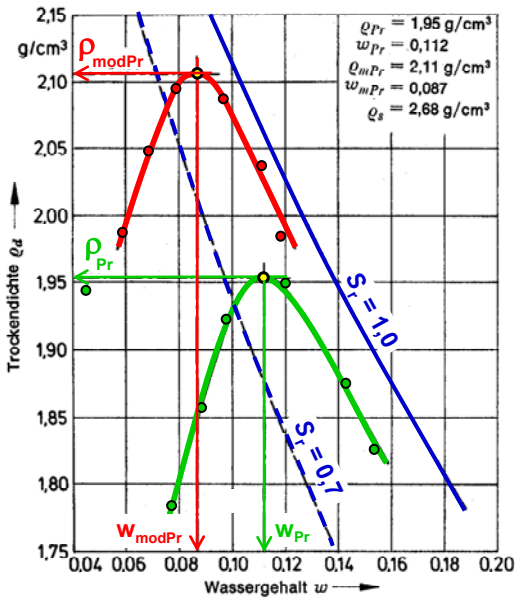
# Embankment Materials



## Relationship Water Content – Dry Density




## Proctor Test




**Standard** **Modified**

**Proctor Test**

Proctor mould Ø150 mm

falling height 450 mm

falling weight 4.5 kg

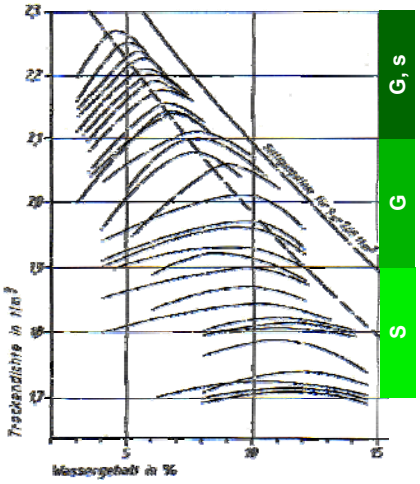
22 blows/layer 59

3 layers 5

0.6 energy [MJ/m³] 2.65

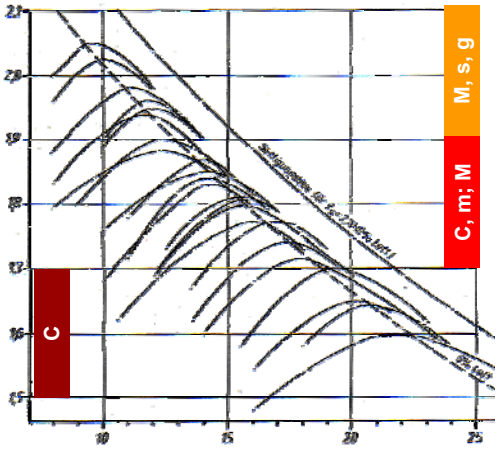
mod $\rho_{Pr}$ = 1.03 …1.15 $\rho_{Pr}$

## Proctor Curves of Different Types of Soils




COARSE GRAINED MATERIALS

FINE GRAINED MATERIALS




## Compaction Control – Spot Testing Methods

**DIRECT**

↓

**DENSITY**

| in-situ | laboratory |
|---|---|
| replacement methods (sand, water, balloon), nuclear gauge probe | Proctor Test |
| ↓ | ↓ |
| dry density $\rho_d$ | Standard Proctor density $\rho_{Pr}$ |

↓

**COMPACTION DEGREE**

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

**INDIRECT**

↓

**STIFFNESS**

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

↓

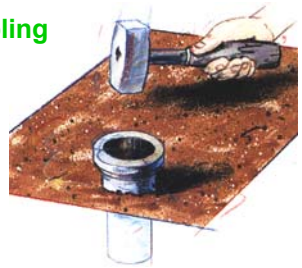
**DEFORMATION MODULUS**

| static | dynamic |
|---|---|
| ↓ | ↓ |
| $E_{v1}$, $E_{v2}$, $E_{v2}/E_{v1}$ | $E_{vd}$ |

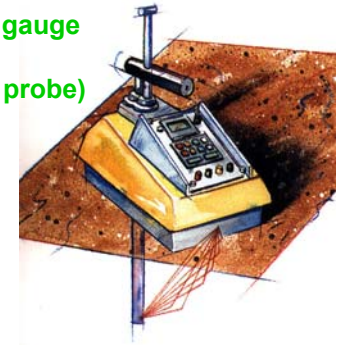
## Determination of Density in Field

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 $\rho_d$
- Proctor Test → Standard Proctor density $\rho_{Pr}$

**INDIRECT** → **STIFFNESS**

- California Bearing Ratio (CBR)
- load plate test → **DEFORMATION MODULUS**
  - static → $E_{v1}$, $E_{v2}$, $E_{v2}/E_{v1}$
  - dynamic → $E_{vd}$
- Benkelman Beam

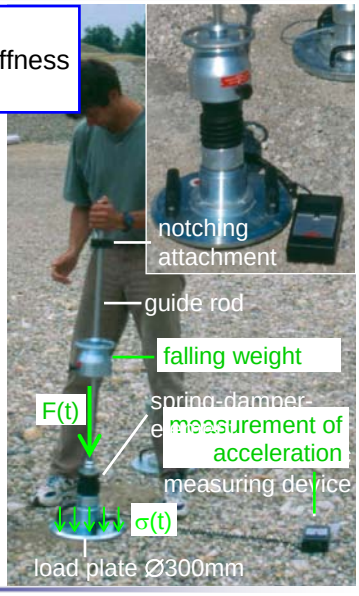
**COMPACTION DEGREE**

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

## Compaction Control Methods using Load Plate Tests

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

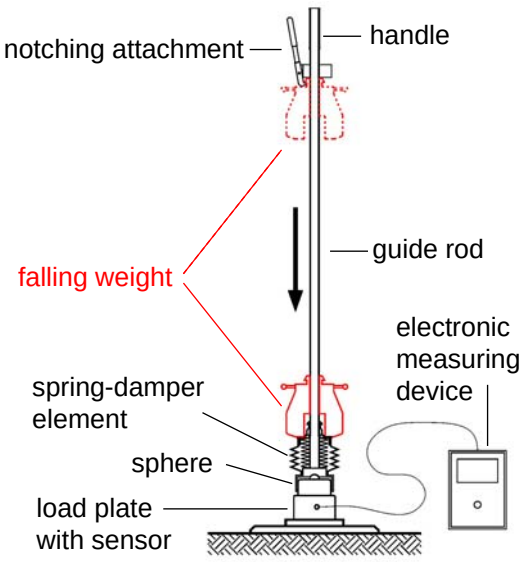
**Static** load plate test



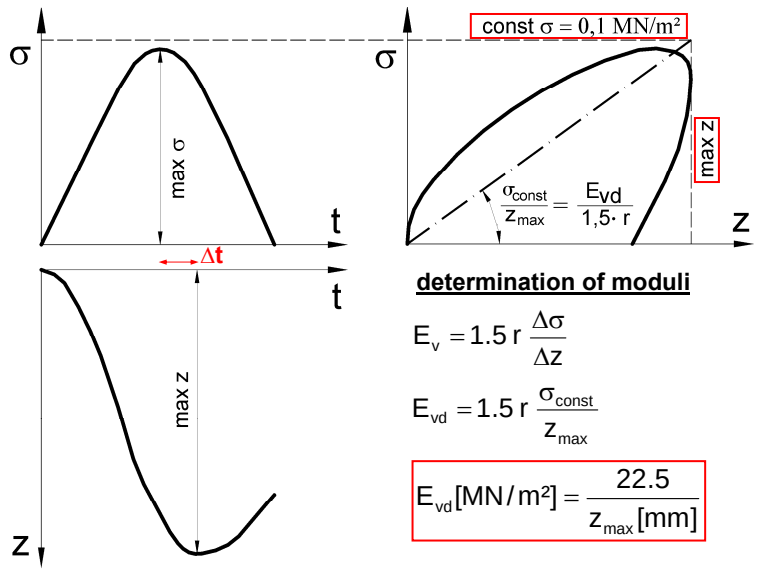

**Dynamic** load plate test with the **L**ight **F**alling **W**eight **D**evice



## 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 **$E_{vd}$ = 10 – 90 MN/m²**

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

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

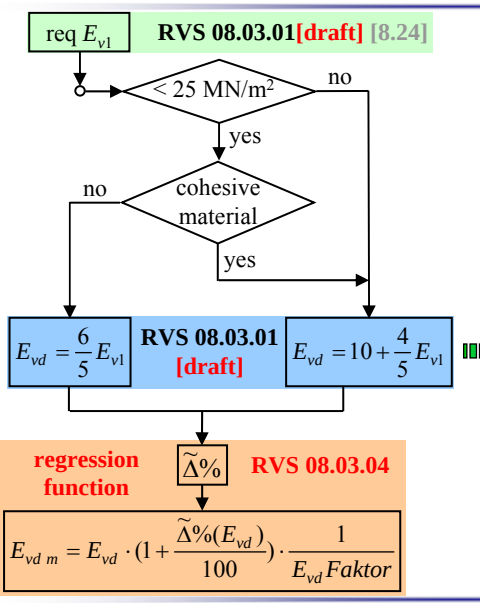
\+ → simplified determination of the dynamic deformation modulus ($E_{vd}$)

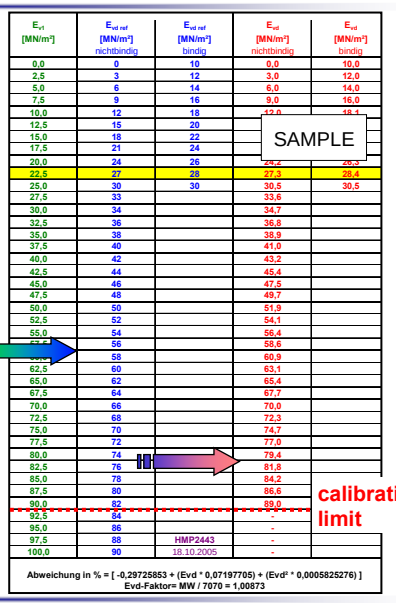
\+ → measuring depth (2 x plate diameter), lateral angle of influence (40°)

~ → 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




| $E_{v1}$ [MN/m²] | $E_{vd\,ref}$ [MN/m²] nichtbindig | $E_{vd\,ref}$ [MN/m²] bindig | $E_{vd}$ [MN/m²] nichtbindig | $E_{vd}$ [MN/m²] bindig |
|---|---|---|---|---|
| 0,0 | 0 | 10 | 0,0 | 10,0 |
| 2,5 | 3 | 12 | 3,0 | 12,0 |
| 5,0 | 6 | 14 | 6,0 | 14,0 |
| 7,5 | 9 | 16 | 9,0 | 16,0 |
| 10,0 | 12 | 18 | | |
| 12,5 | 15 | 20 | | |
| 15,0 | 18 | 22 | | |
| 17,5 | 21 | 24 | | |
| 20,0 | 24 | 26 | | |
| 22,5 | 27 | 28 | 27,3 | 28,4 |
| 25,0 | 30 | 30 | 30,5 | 30,5 |
| 27,5 | 33 | | 33,6 | |
| 30,0 | 34 | | 34,7 | |
| 32,5 | 36 | | 36,8 | |
| 35,0 | 38 | | 38,9 | |
| 37,5 | 40 | | 41,0 | |
| 40,0 | 42 | | 43,2 | |
| 42,5 | 44 | | 45,4 | |
| 45,0 | 46 | | 47,5 | |
| 47,5 | 48 | | 49,7 | |
| 50,0 | 50 | | 51,9 | |
| 52,5 | 52 | | 54,1 | |
| 55,0 | 54 | | 56,4 | |
| 57,5 | 56 | | 58,6 | |
| 60,0 | 58 | | 60,9 | |
| 62,5 | 60 | | 63,1 | |
| 65,0 | 62 | | 65,4 | |
| 67,5 | 64 | | 67,7 | |
| 70,0 | 66 | | 70,0 | |
| 72,5 | 68 | | 72,3 | |
| 75,0 | 70 | | 74,7 | |
| 77,5 | 72 | | 77,0 | |
| 80,0 | 74 | | 79,4 | |
| 82,5 | 76 | | 81,8 | |
| 85,0 | 78 | | 84,2 | |
| 87,5 | 80 | | 86,6 | |
| 90,0 | 82 | | 89,0 | |
| 92,5 | 84 | | - | |
| 95,0 | 86 | | - | |
| 97,5 | 88 | HMP2443 | - | |
| 100,0 | 90 | 18.10.2005 | - | |

Abweichung in % = [ -0,29725853 + (Evd * 0,07197705) + (Evd² * 0,0005825276) ]
Evd-Faktor= MW / 7070 = 1,00873



# 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 $D_{Pr}$:**

   determination of Proctor density $\rho_{Pr}$ — **ÖNORM B 4414-2**
   + determination of density in field $\rho_d$ — **DIN 18125-2**
   3.1 sand replacement — **Bulletin FGSV**
   3.2 water replacement — **ÖNORM B 4418**
   3.3 nuclear gauge probe

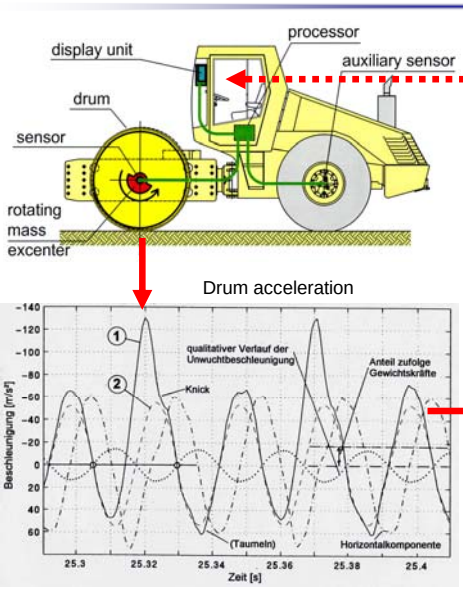
other control methods:

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

**when area of subgrade level ≥ 30,000 m²**

**Bulletin FGSV**
**ÖNORM B 4405 + B 4419**

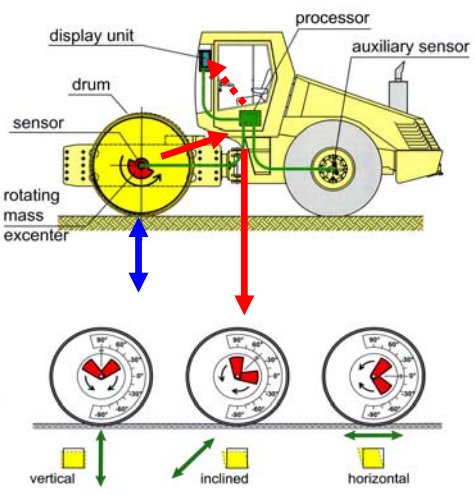
# Continuous Compaction Control (CCC)





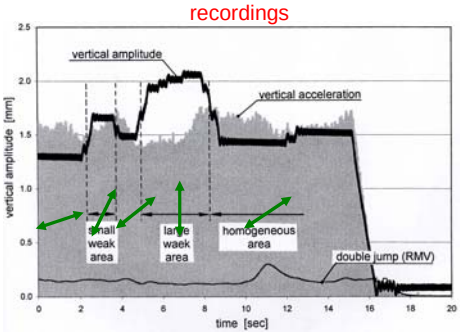


# Automatically Controlled Compaction

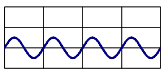
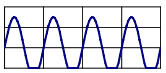
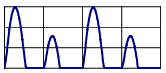
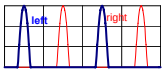
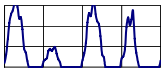



automatic inclination of exciter unit


recordings



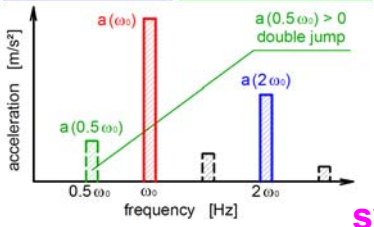
# Operating Modes of Vibratory Roller Drums

| 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 |



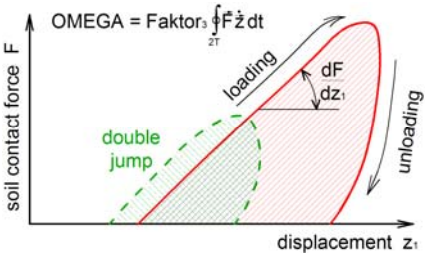
**Compactometer** – ***CMV*** is based on the evaluation of the acceleration in the *frequency domain*

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



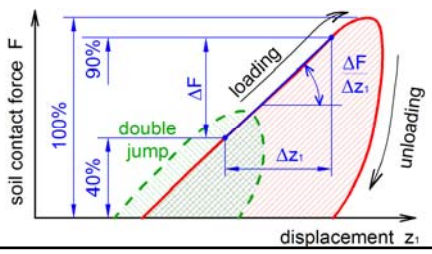

**Terrameter** – ***OMEGA*** is based on the evaluation of the energy transmitted to the soil in the *time domain*

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

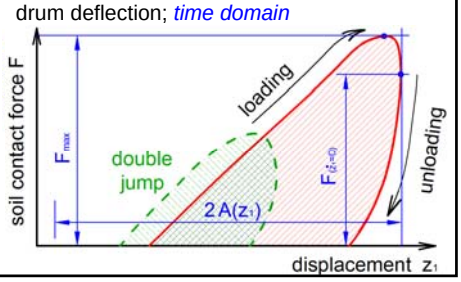



## CCC-systems

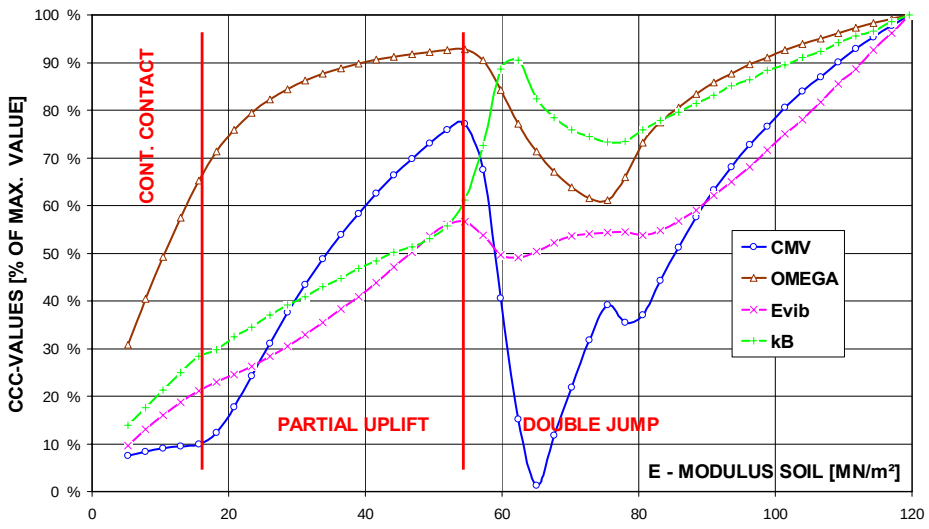
**Terrameter** – $E_{VIB}$ ⇨ inclination of the soil contact force displacement relationship during loading; *time domain*




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

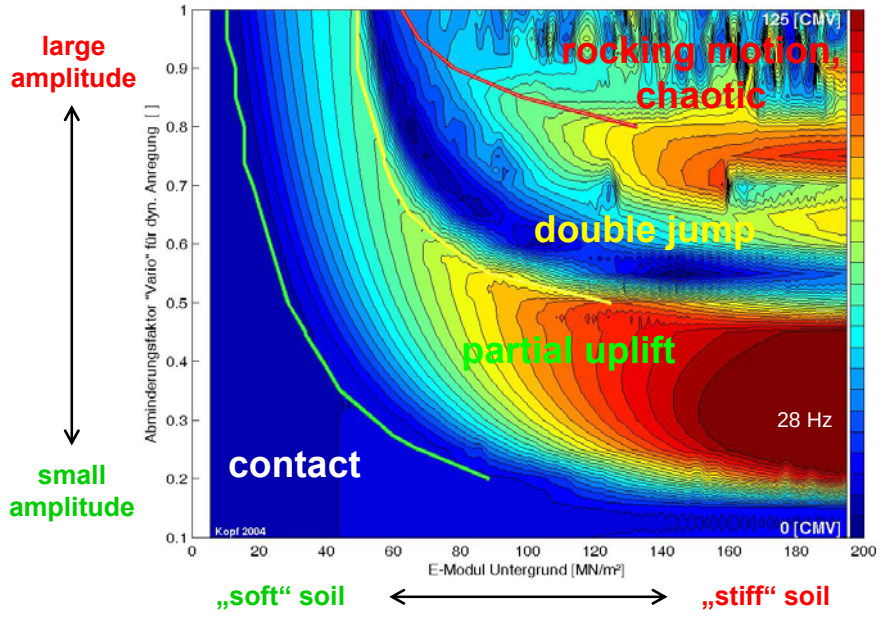


## CCC-values – CMV, OMEGA, $E_{vib}$, $k_B$

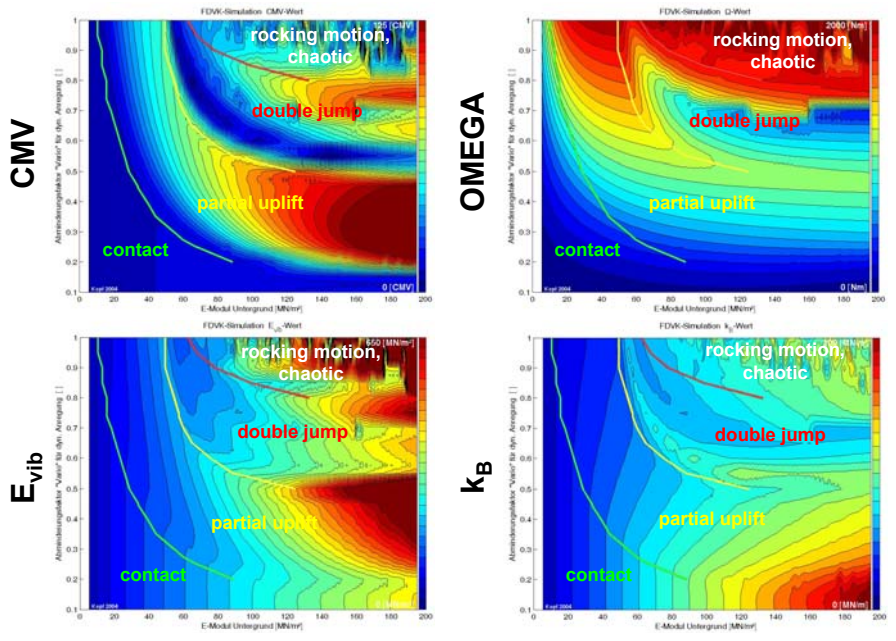




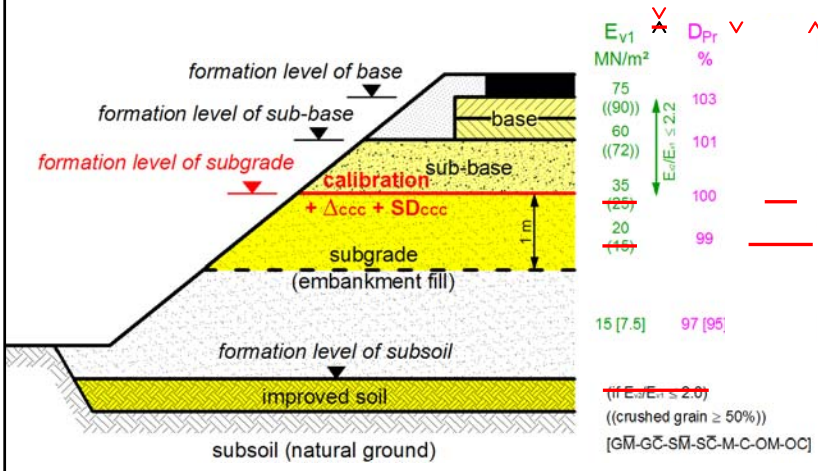

## CMV in Dependence of the Operating Conditions



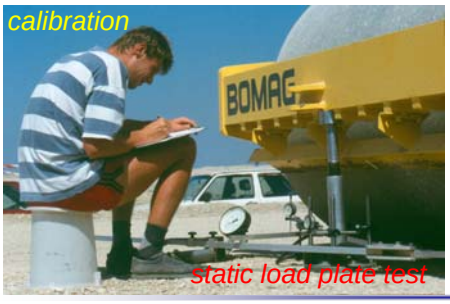
# Comparison of Different CCC-Values

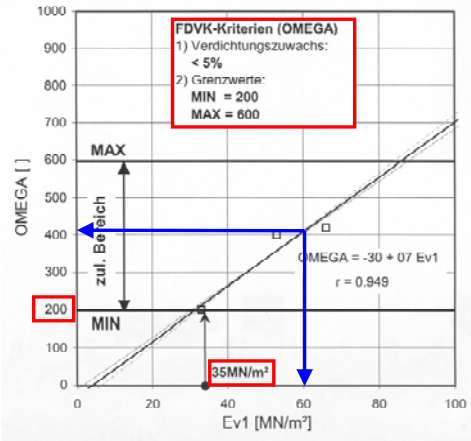



# Earth Work ⇨ RVS 08.03.01[draft] [8.24]



# Continuous Compaction Control (CCC)

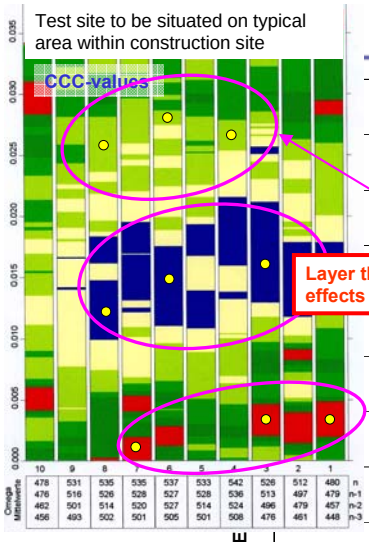



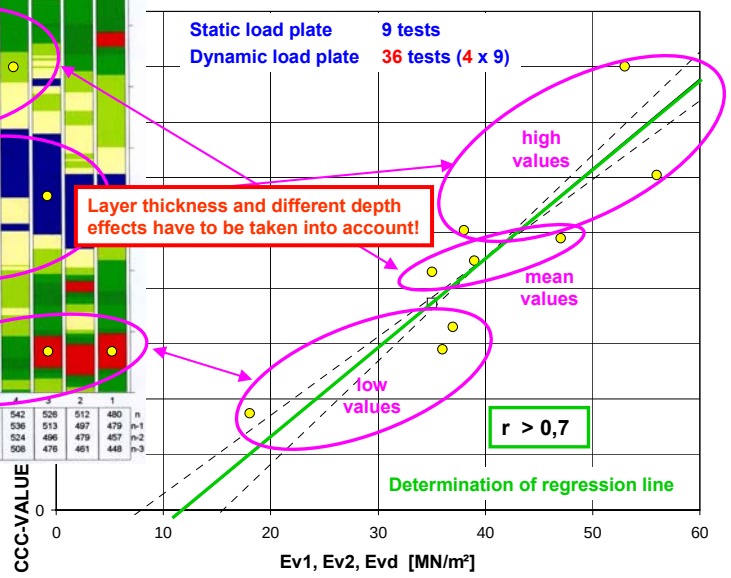

## Calibration of CCC-values

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

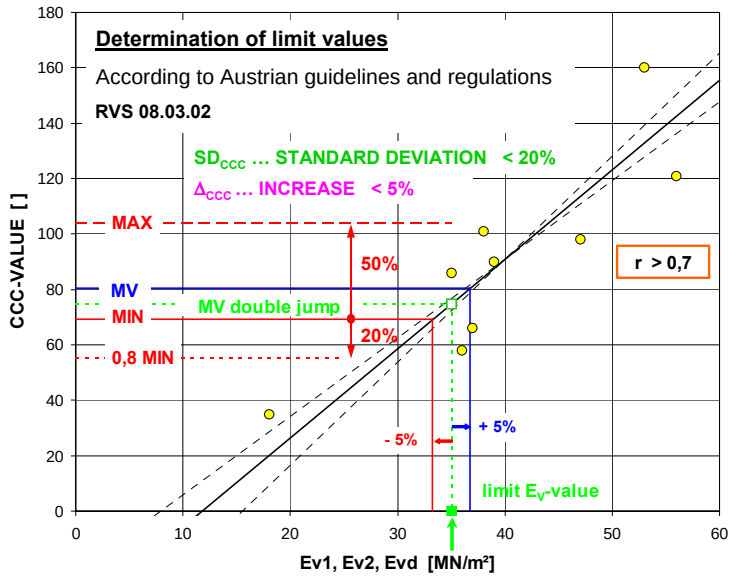


# Calibration of CCC-values



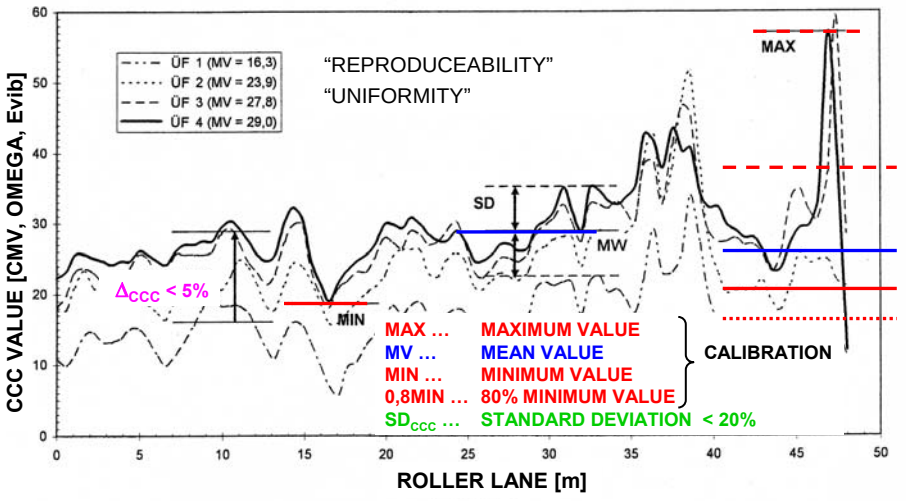



# Calibration of CCC-values





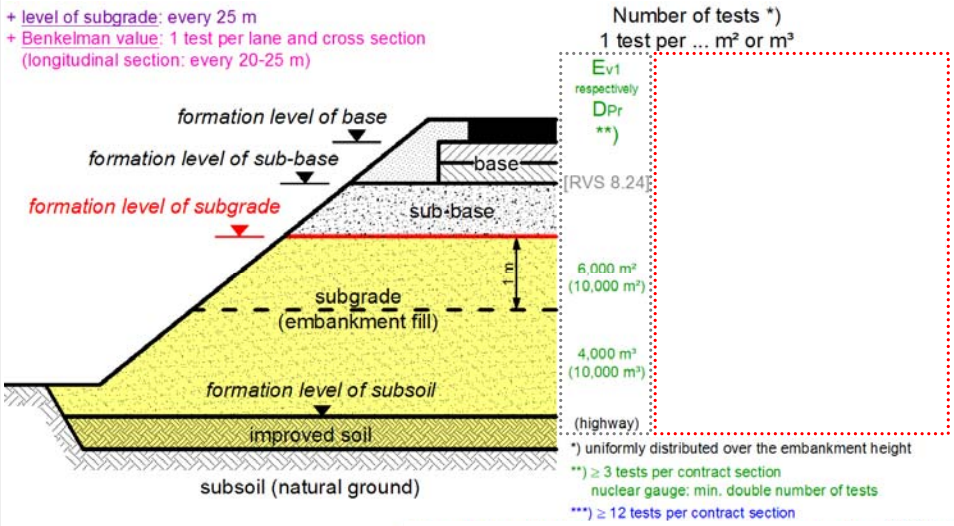

# Continuous Compaction Control (CCC)



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

**subgrade (RVS 08.03.01[draft] [8.24])**

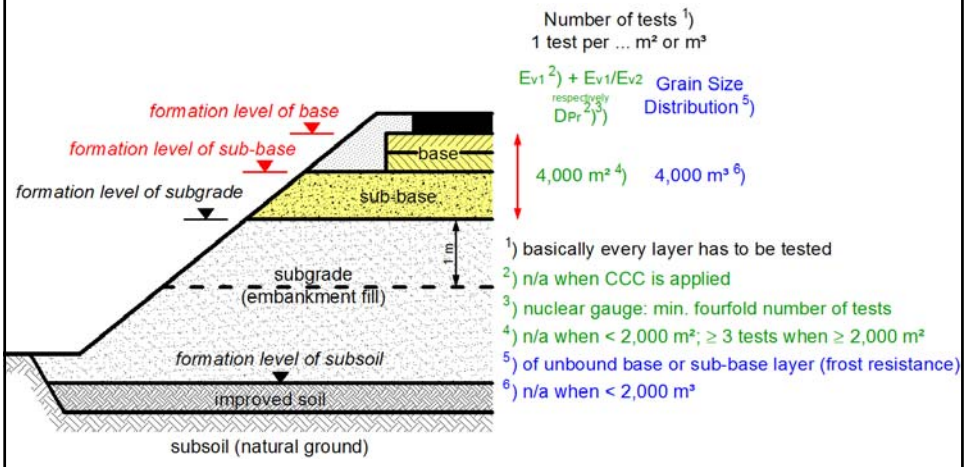
+ level of subgrade: every 25 m
+ Benkelman value: 1 test per lane and cross section (longitudinal section: every 20-25 m)

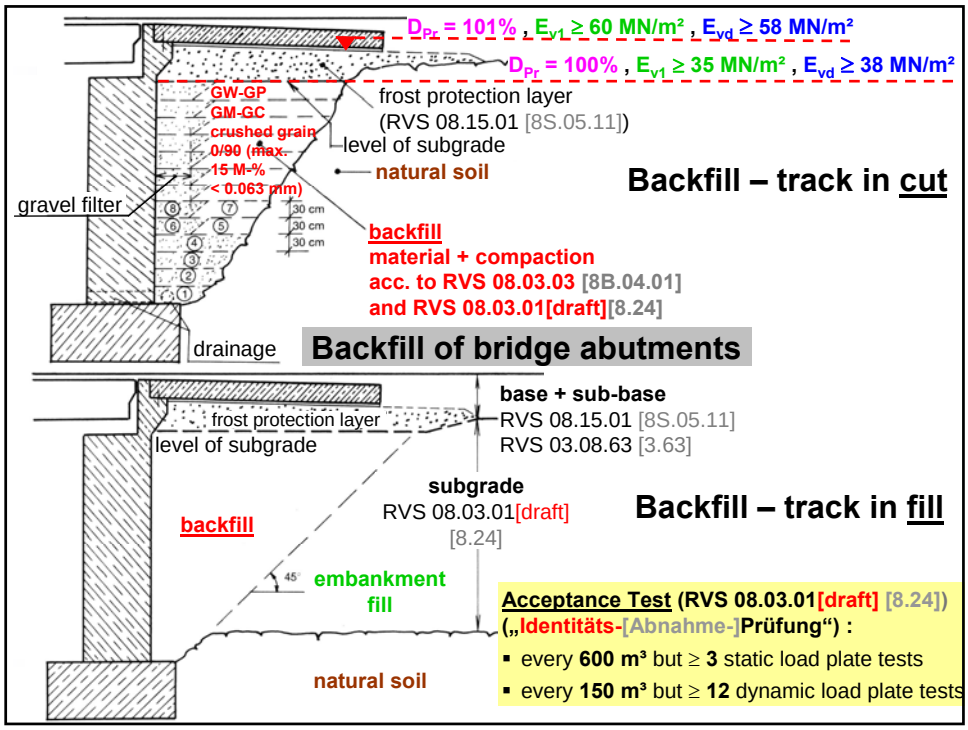


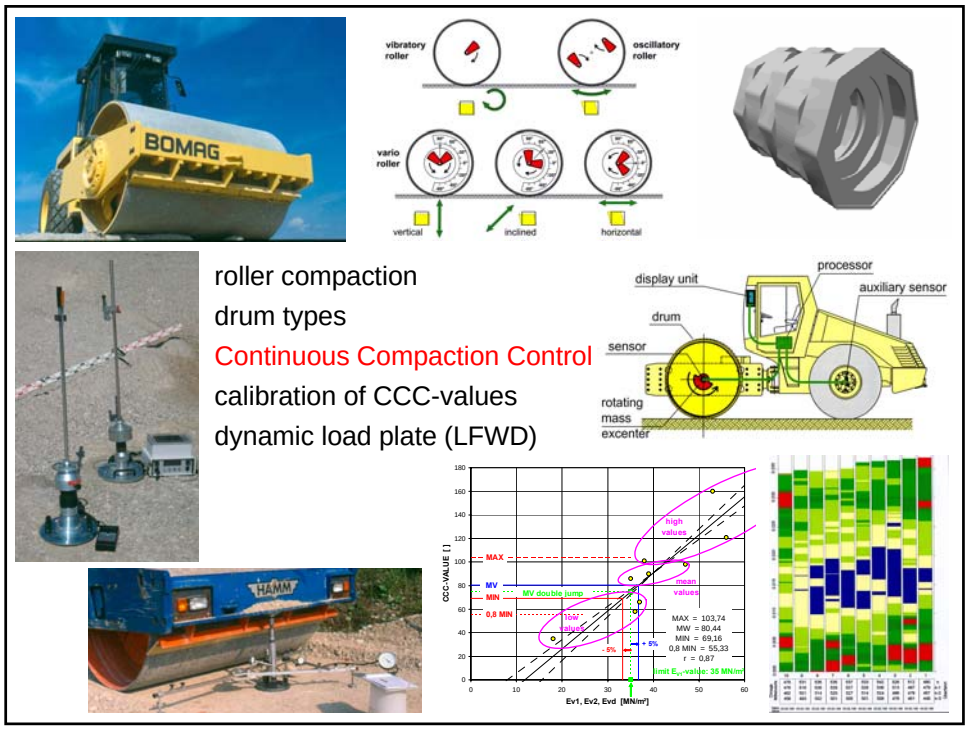



## Acceptance Test („Identitäts-[Abnahme-]Prüfung“)

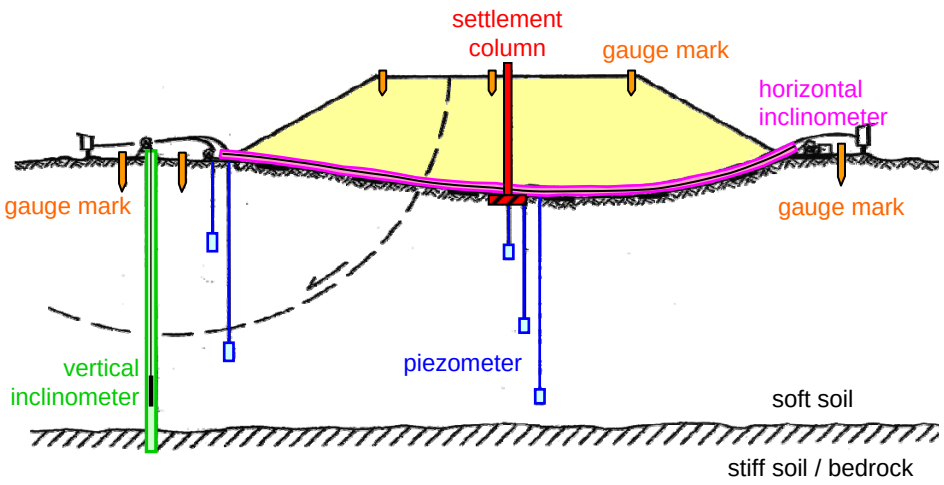
**base and sub-base (RVS 08.15.01 [8S.05.11])**




$D_{Pr}$ = 101% , $E_{v1}$ ≥ 60 MN/m² , $E_{vd}$ ≥ 58 MN/m²
$D_{Pr}$ = 100% , $E_{v1}$ ≥ 35 MN/m² , $E_{vd}$ ≥ 38 MN/m²
GW-GP
GM-GC
crushed grain
0/90 (max. 15 M-% < 0.063 mm)
frost protection layer
(RVS 08.15.01 [8S.05.11])
level of subgrade
natural soil
Backfill – track in cut
gravel filter
30 cm
30 cm
30 cm
backfill
material + compaction
acc. to RVS 08.03.03 [8B.04.01]
and RVS 08.03.01[draft][8.24]
drainage
Backfill of bridge abutments
base + sub-base
RVS 08.15.01 [8S.05.11]
RVS 03.08.63 [3.63]
frost protection layer
level of subgrade
subgrade
RVS 08.03.01[draft]
[8.24]
backfill
Backfill – track in fill
45°
embankment
fill
natural soil
Acceptance Test (RVS 08.03.01[draft] [8.24])
(„Identitäts-[Abnahme-]Prüfung“) :
every 600 m³ but ≥ 3 static load plate tests
every 150 m³ but ≥ 12 dynamic load plate tests

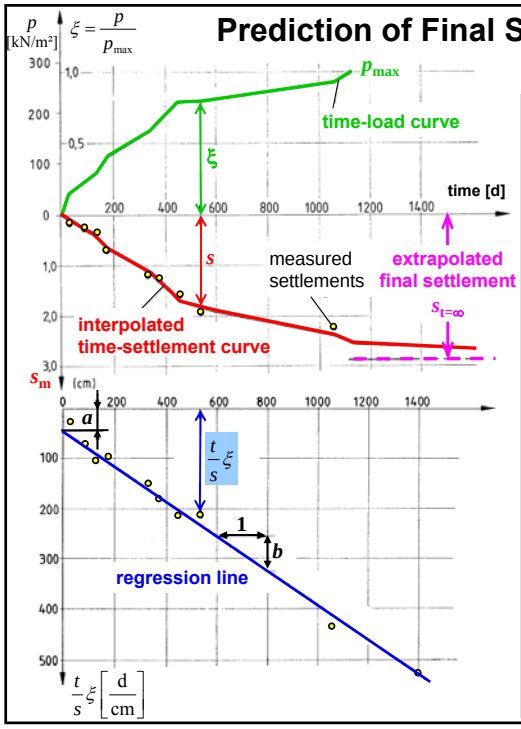

BOMAG
vibratory roller
oscillatory roller
vario roller
vertical
inclined
horizontal
roller compaction
drum types
Continuous Compaction Control
calibration of CCC-values
dynamic load plate (LFWD)
display unit
processor
auxiliary sensor
drum
sensor
rotating mass excenter
HAMM
CCV-VALUE [-]
MAX
MV
MIN
0,8 MIN
MV double jump
high values
mean values
MAX = 103,74
MW = 80,44
MIN = 69,16
0,8 MIN = 55,33
r = 0,87
Ev1, Ev2, Evd [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