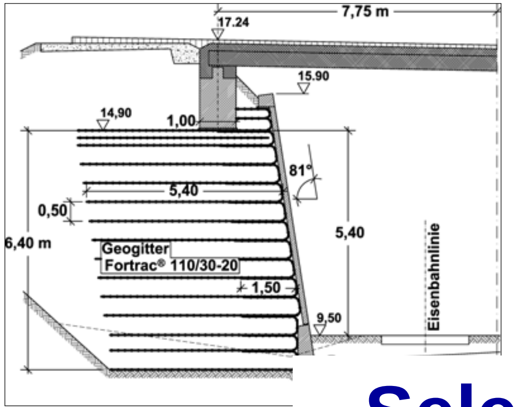
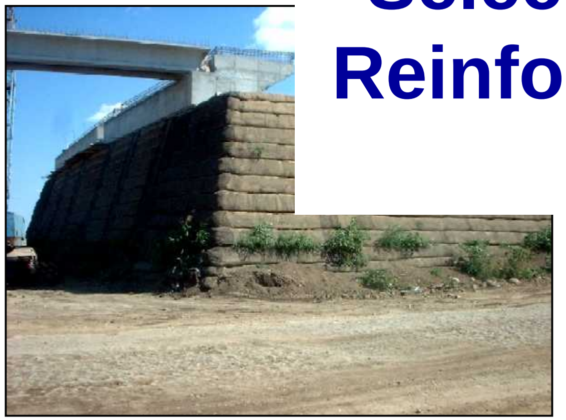


Selected Topics: Geosynthetic Reinforcement in Transportation Engineering



Dr. Dimiter Alexiew

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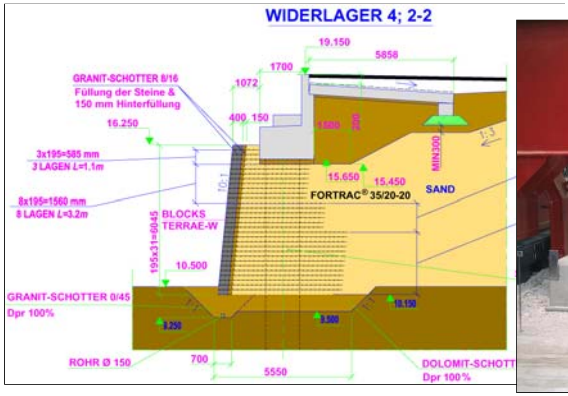
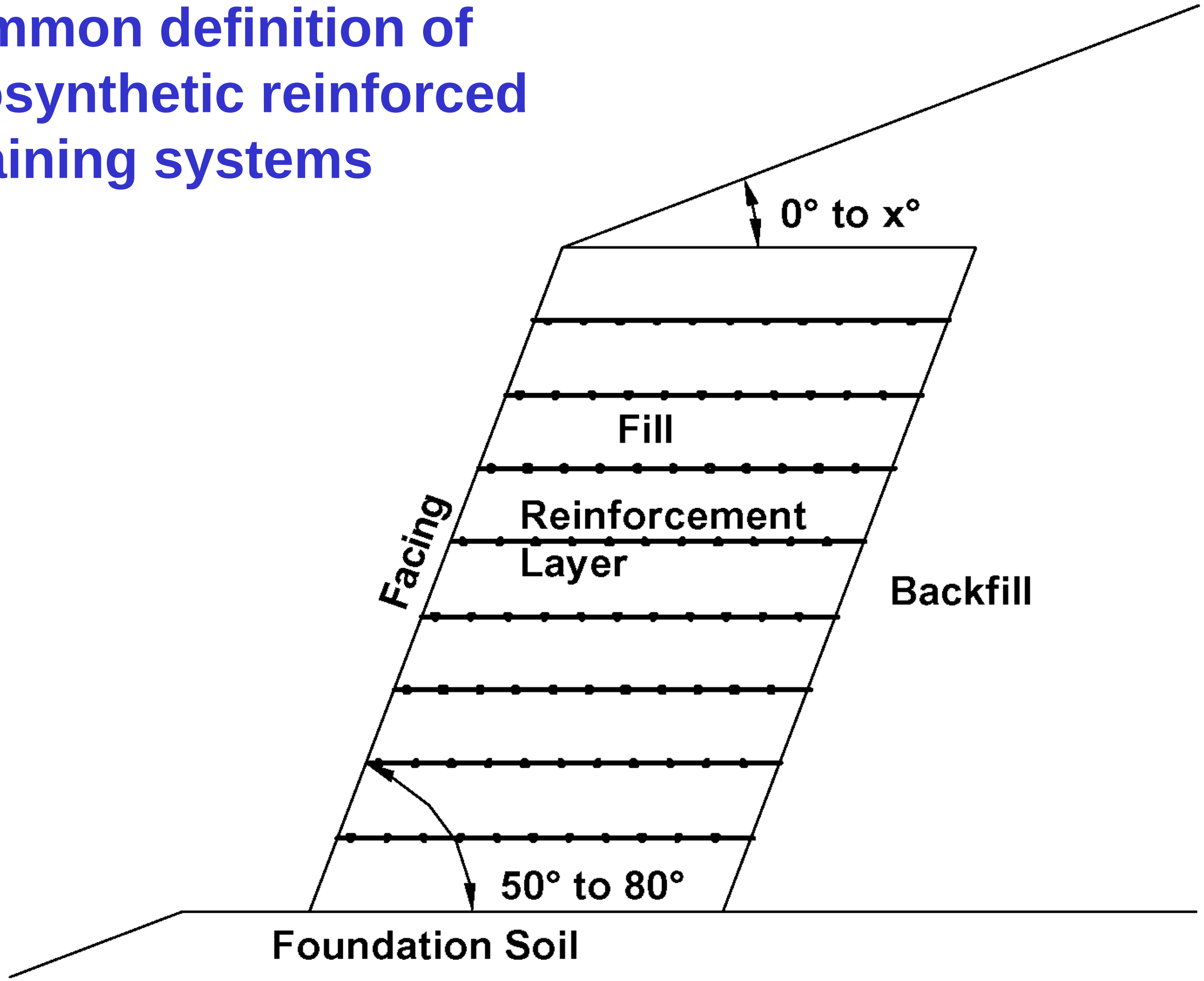


Bridge abutments

Common definition of geosynthetic reinforced retaining systems



To the definition of geosynthetic reinforced slopes and walls

In some codes and recommendations:

max 70° inclination of the front to the horizontal.

Steeper systems: “walls”.

Different design procedures for “slopes” and “walls”.

No reason for such an artificial distinguishing!

68°….72° ????

Japan, new German Code EBGEO 2007: same procedures!

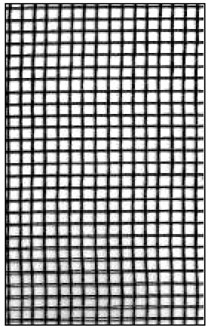
The systems are in the meantime very popular and are becoming very common with increasing tendency:

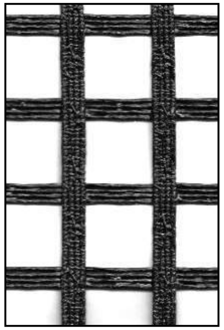
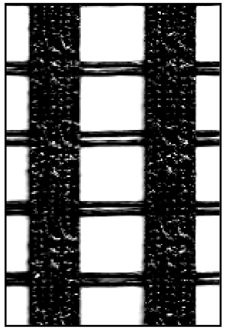
- **Very adaptive shape:**
  Geometry, inclination, facing, curvature etc.
- **Fitting the landscape**
- **Ductile behavior**
- **Easy construction**
- **Cost efficient**

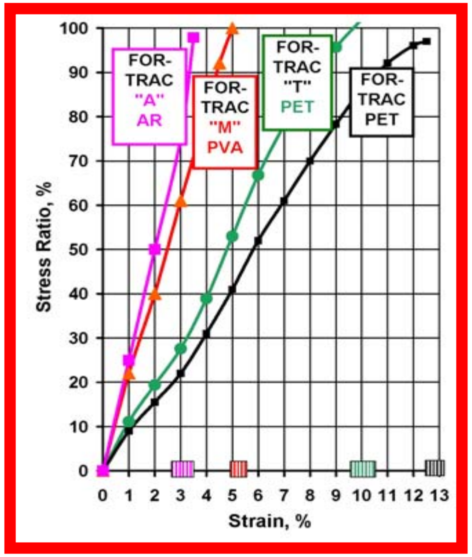
Geosynthetic reinforcement

- **Geogrids**

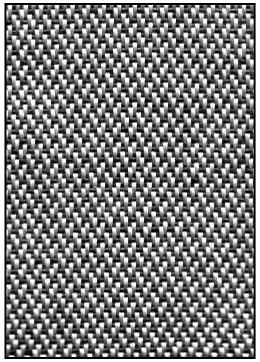
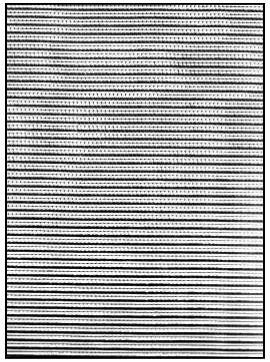
~ 2 cm



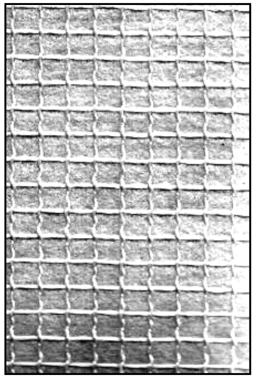
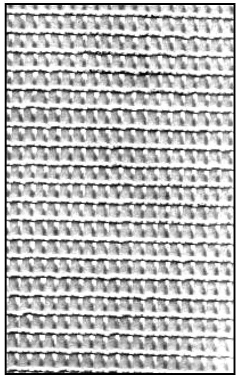





- **Wovens**

- **Geocomposites**

Geosynthetic reinforcement

The geotechnical engineer's ideal geosynthetic reinforcement:

- **High tensile modulus (tensile stiffness) short- and long-term (but not too high…)**
- **Low propensity to creep (high long-term strength and minimum creep strain)**
- **High bond coefficient with the soil in both shear- and pull-out modes (short anchorage lengths, good interaction between reinforcement and soil)**

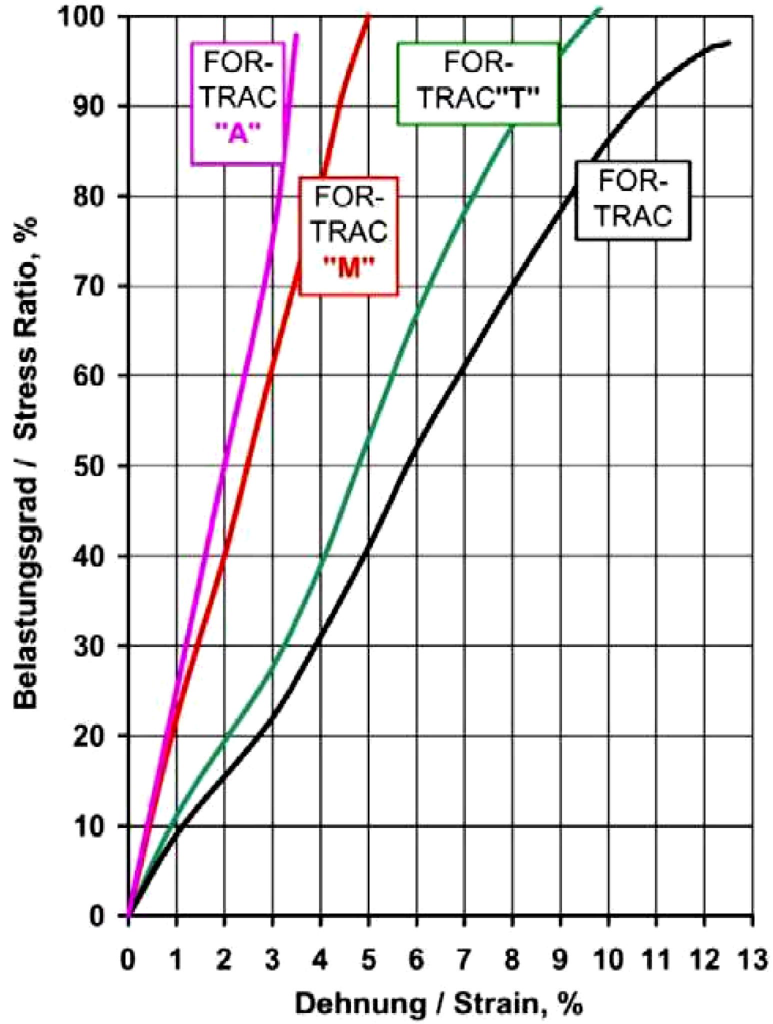
Geosynthetic reinforcement

- Very **high permeability** (lowest hydraulic resistance and as a result, no increasing water pressure problems)
- **Low damage** during installation and soil compaction
- **High chemical and biological resistance in all conceivable environments**
- Low costs

Geosynthetic reinforcement

Unfortunately, the ideal reinforcement does not exist yet.

Nevertheless, geotechnical engineers have today the fortunate possibility to choose an optimal reinforcement always and for any case due to the wide range of materials available: wovens, geocomposites and geogrids made of different polymers.



Geosynthetic reinforcement
Polymers: appropriate mechanical behavior

Vereinfachte Klassifizierung
Simplified Classification

- ✦✦✦✦ bestens / excellent
- ✦✦✦ sehr gut / very suitable
- ✦✦ gut / suitable
- ✦ mäßig / modest

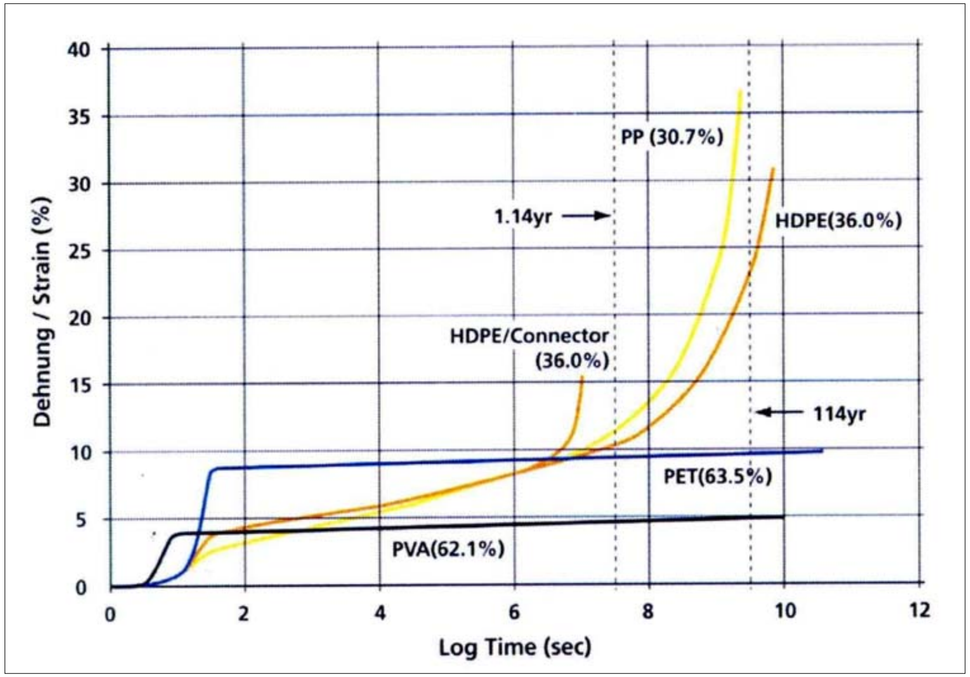
		Kurzzeitmodul (Eine - Minute - Test) Short - term module (one - minute - test)	
		sehr hoch very high	hoch high
Langzeitmodul (nach Kriechen) Long-term module (after creep)	hoch high	**Aramid & PVA** ✦✦✦✦	**PETP (PES) hochfest** ✦✦✦
	gering low	**PP & HDPE** ✦✦	**PP & PE** ✦

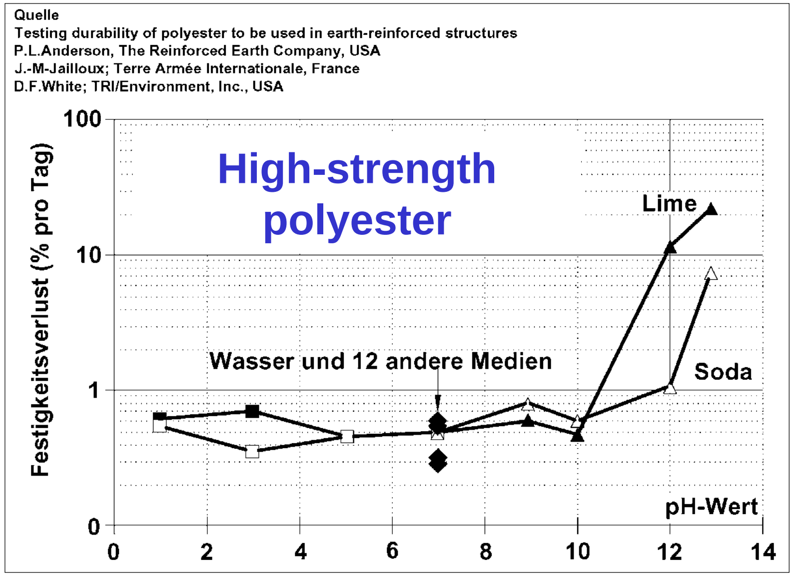
Design strength geosynthetics (ULS)

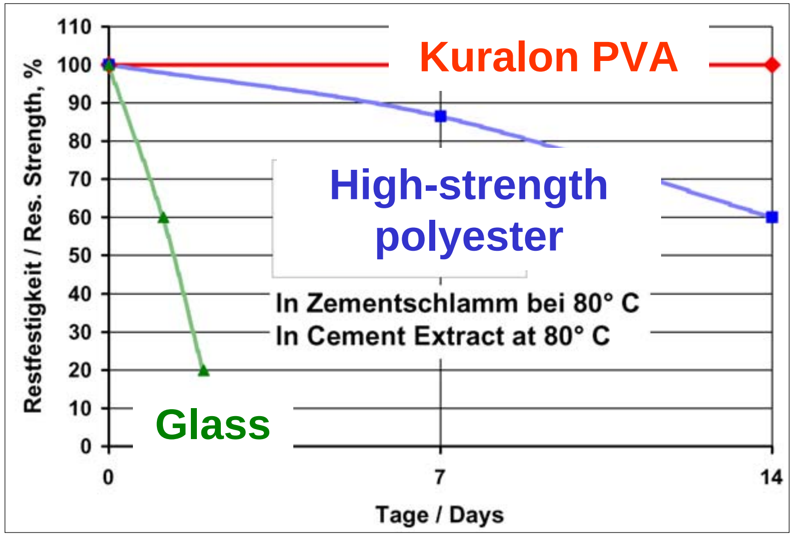
$$F_d = UTS / (RF_{creep} \times RF_{instdem} \times RF_{env} \times RF_{joint} \times „X“)$$

Fd	kN/m	design strength
UTS	kN/m	ultimate tensile strength (guaranteed as produced in plant short-term strength)
RF_{creep}	---	*red.* factor for creep
$RF_{instdem}$	---	*red.* factor for inst. and comp. damage
RF_{env}	---	*red.* factor for chem. & biol. effects
RF_{joint}	---	*red.* factor for seams & joints
„X“	---	add. factor of *safety* for the reinforce-ment, diff. formal names in diff. countries, from 1.0 in USA to 1.75 (1.4) in Germany

Design strength geosynthetics (ULS)





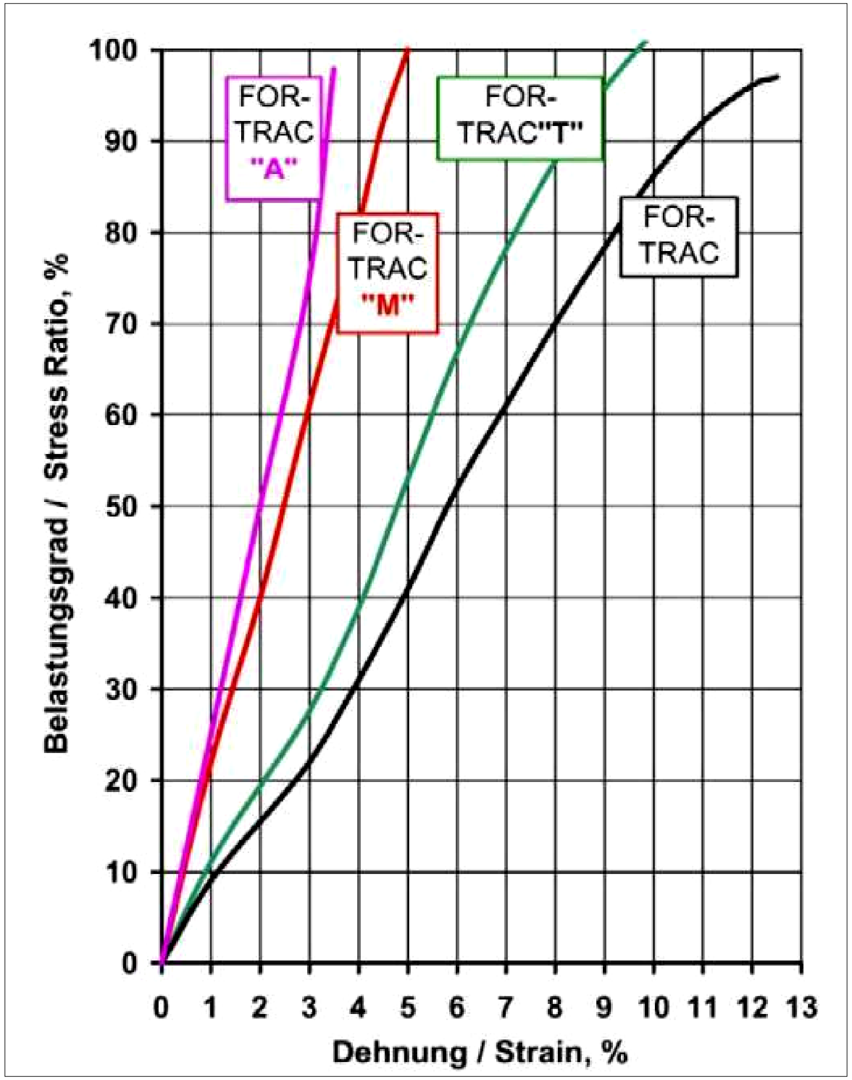


Design strength geosynthetics (ULS)

Obligatory default **values for reduction factors if not tested/certified acc. e.g. to German Codes („Merkblatt" & EBGEO 2007):**

Polymer:	RF_{creep}:	RF_{env}:	$RF_{instdem}$:
AR	3.5	3.3	1.5 to
PA	3.5	3.3	2.0
PET	3.5	2.0	
PVA	3.5	2.0	
PE	6.0	3.3	
PP	6.0	3.3	

Control of deformations via the geosynthetics (SLS)



short-term

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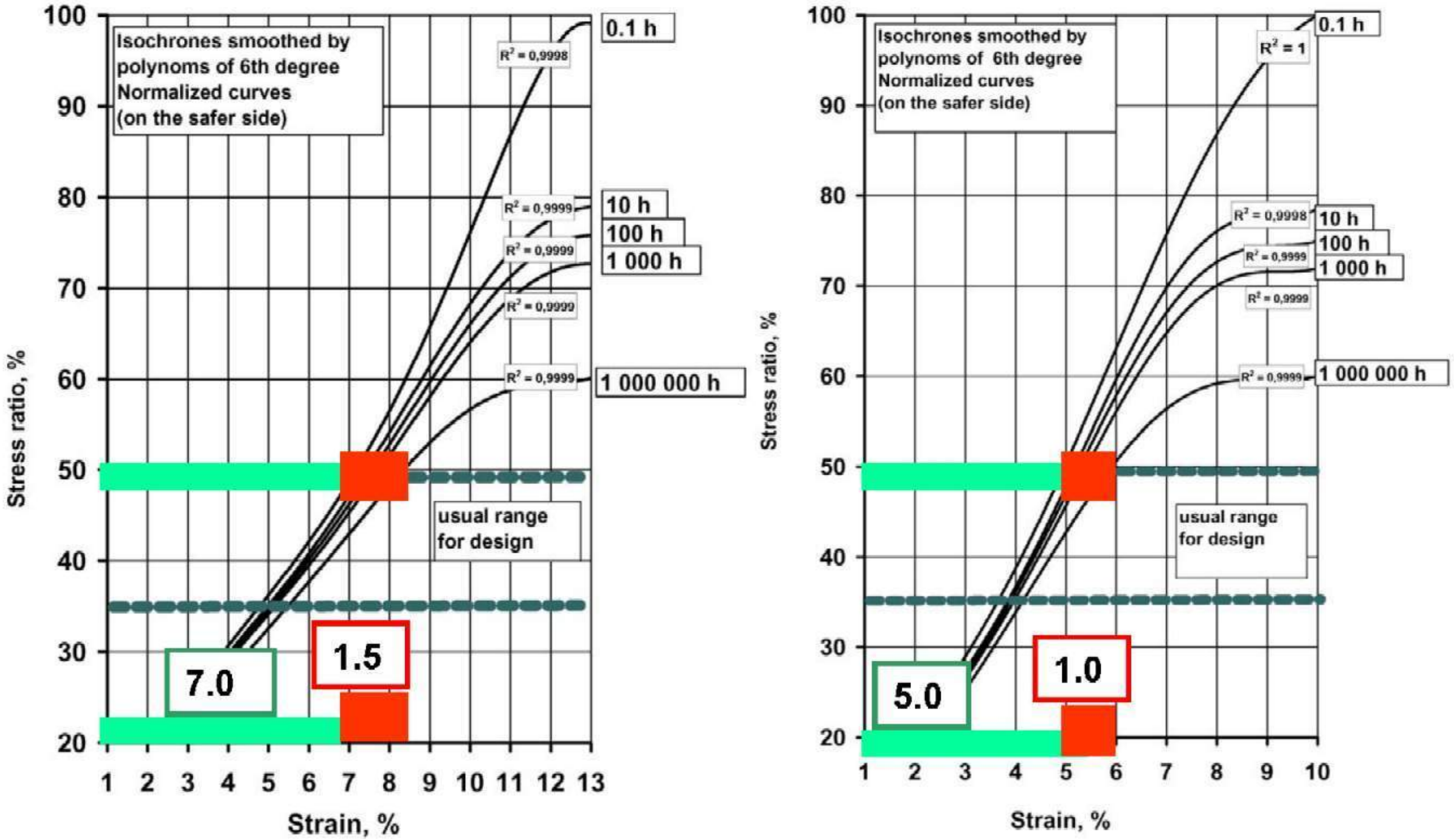
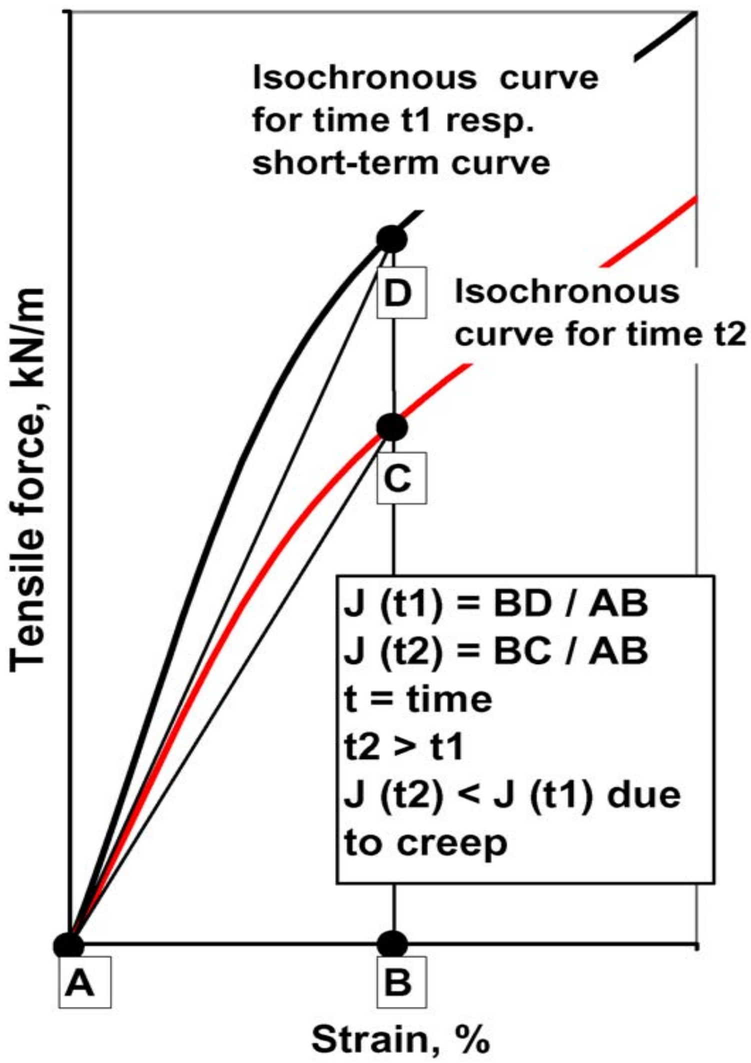
Control of deformations via the geosynthetics (SLS)

long-term & total (isochrones)



Strains vs. Time vs. Stress Ratio

Control of deformations via the geosynthetics (SLS)



long-term & total via the time-dependent tensile modulus

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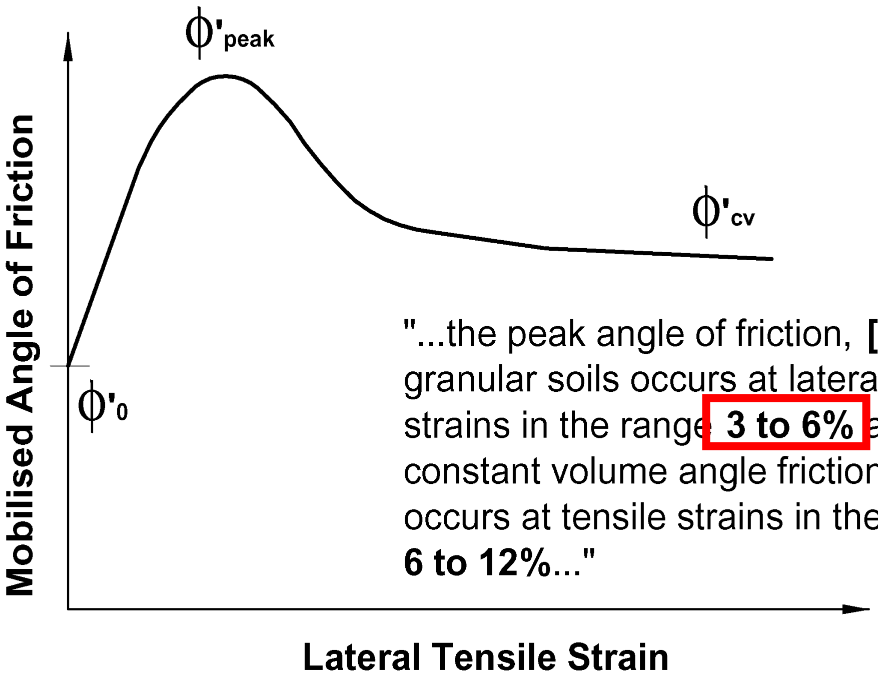
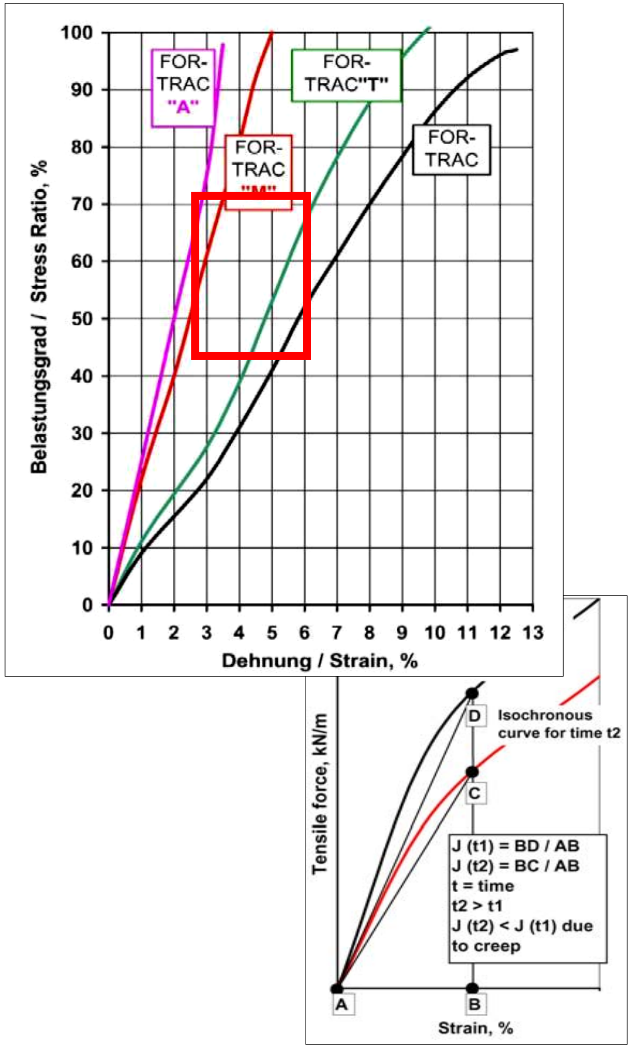
Control of deformations via the geosynthetics (SLS)

Attention…! For walls and slopes…

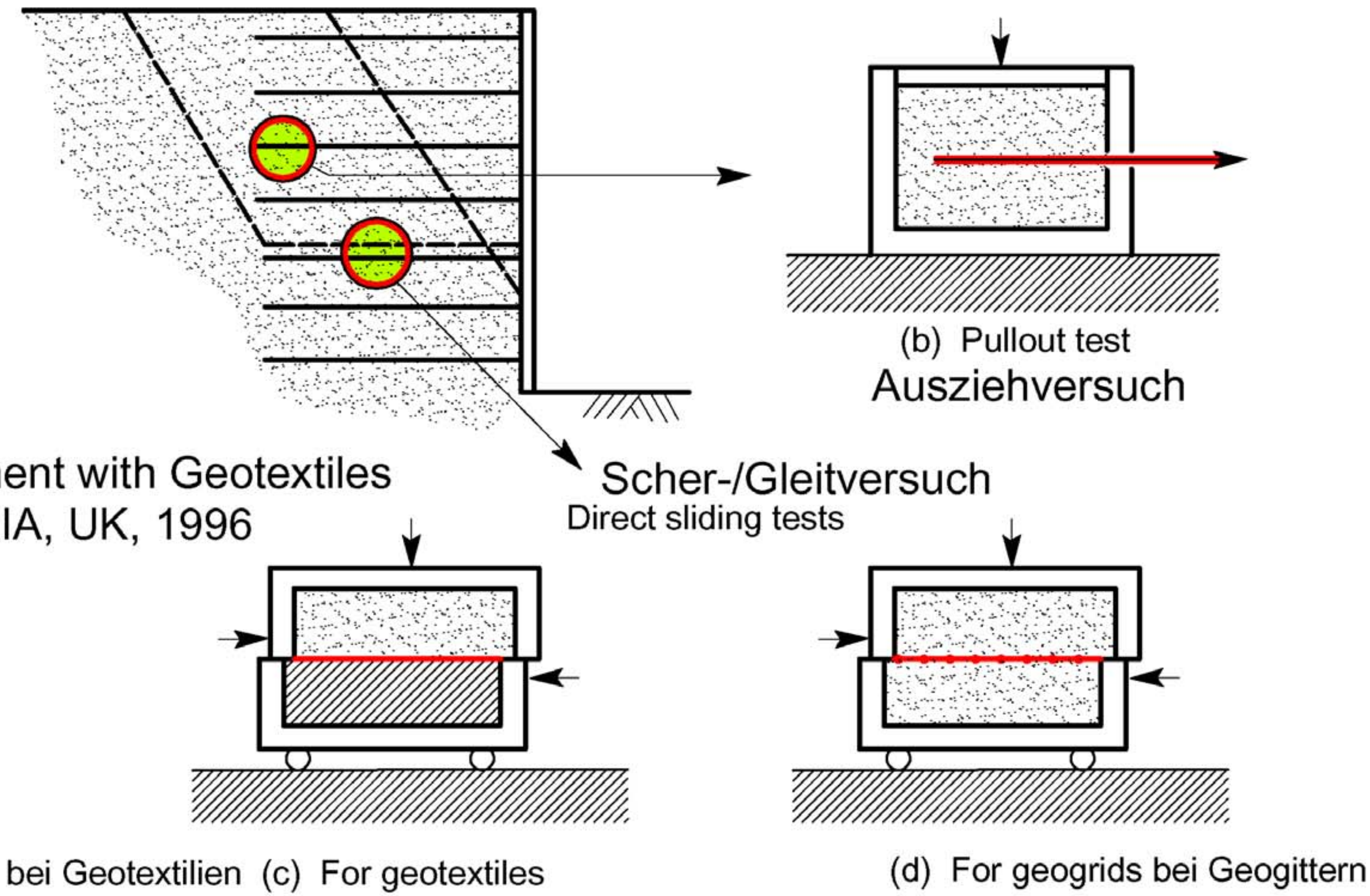
Source: A. McGown, University of Strathclyde, UK
The Behaviour of Geosynthetic Reinforced Soil Systems
in Various Geotechnical Applications
Proc. Euro Geo 2000, Bologna / Italy, pp. 3-23



"...the peak angle of friction, **[ϕ'p]**, for granular soils occurs at lateral tensile strains in the range **3 to 6%** and the constant volume angle friction, **[ϕ'cv]**, occurs at tensile strains in the range **6 to 12%**..."



Coefficients of interaction: pullout and sliding (shear)



Soil Reinforcement with Geotextiles
R.A.Jewell CIRIA, UK, 1996

Coefficients of interaction: pullout and sliding (shear)

$$CI = \frac{\text{shear strength geogrid / soil}}{\text{shear strength soil / soil (internal)}}$$

CI shear mode

CI pull-out mode

CI >= 1.0 → no negative interface effects, "perfect bond"

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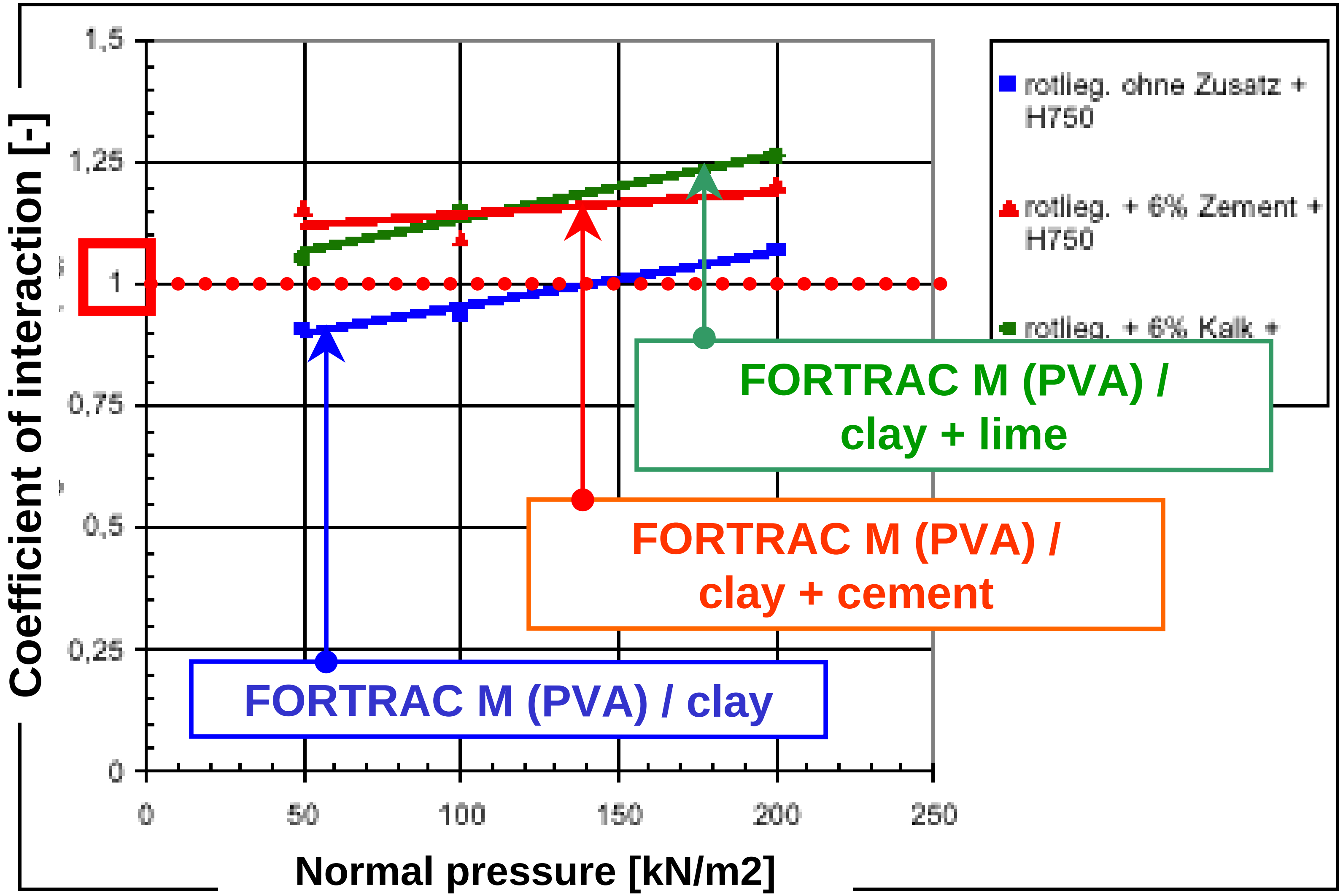
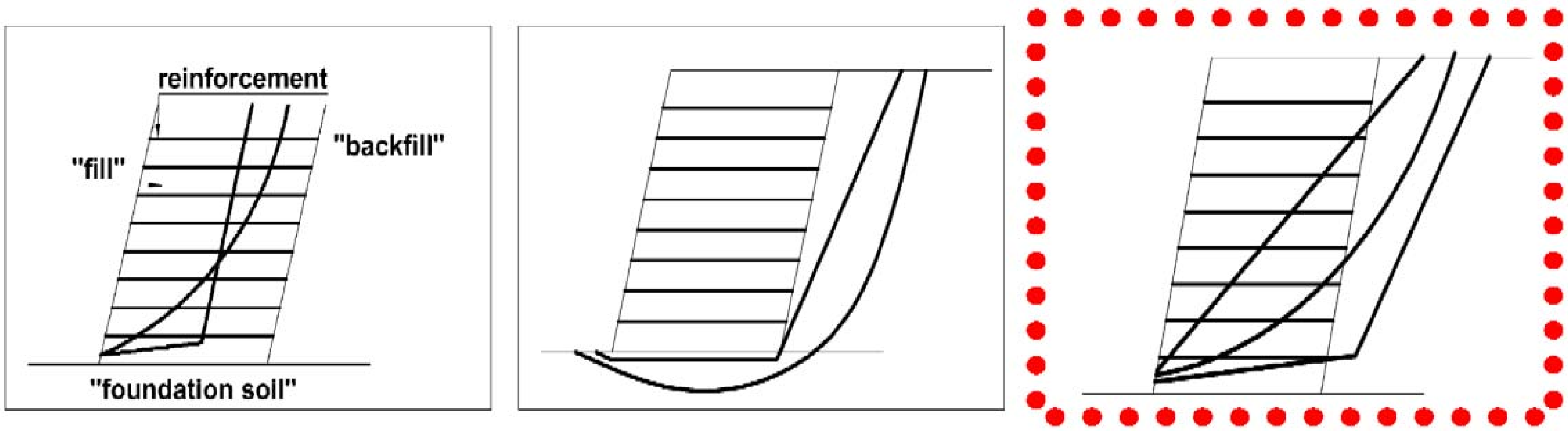
Coefficients of interaction: pullout and sliding (shear)



Modi of failure to be checked



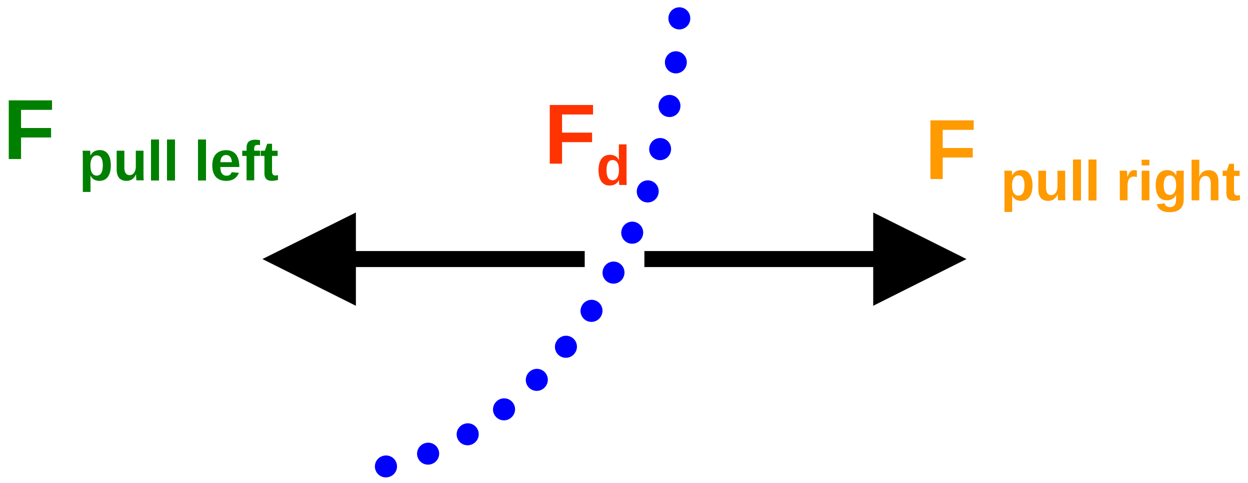
intern extern compound

The well known geotechnical stability design procedures are commonly used e.g. Bishop, Janbu, Block sliding etc. The reinforcement (geogrids) provides additional retaining forces.

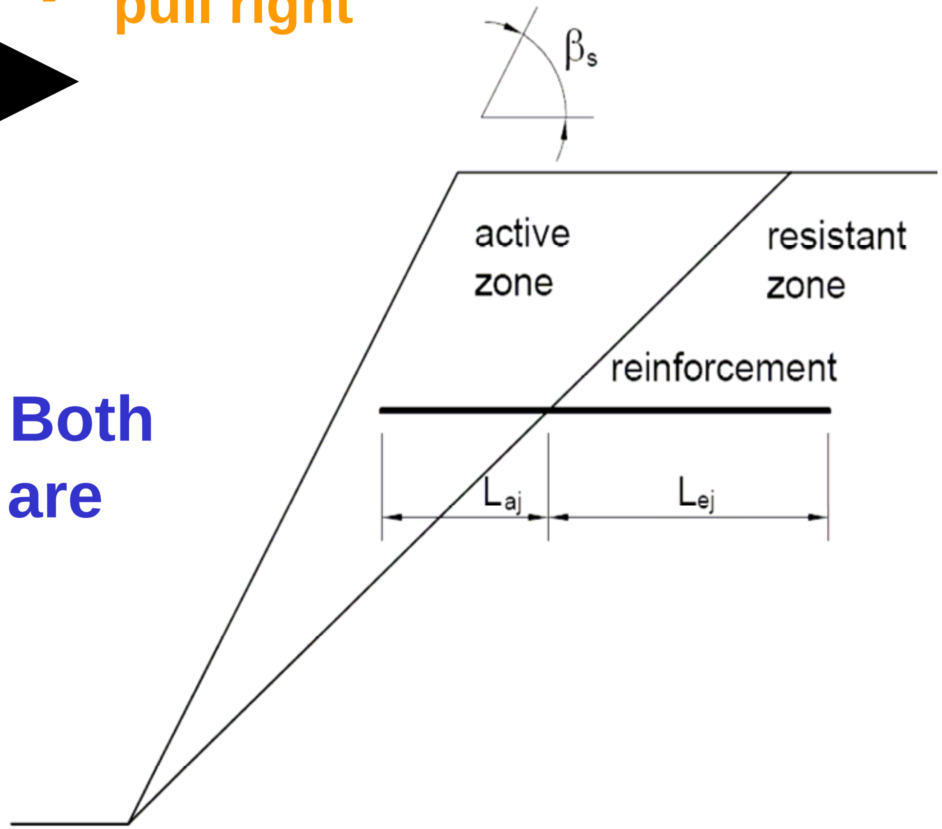
<u>Note:</u> min (F_d , $F_{pull\ left}$, $F_{pull\ right}$)

"Compound" controls often the design, but is <u>not</u> included in many Codes!!! Pay attention! Look also for interface sliding!

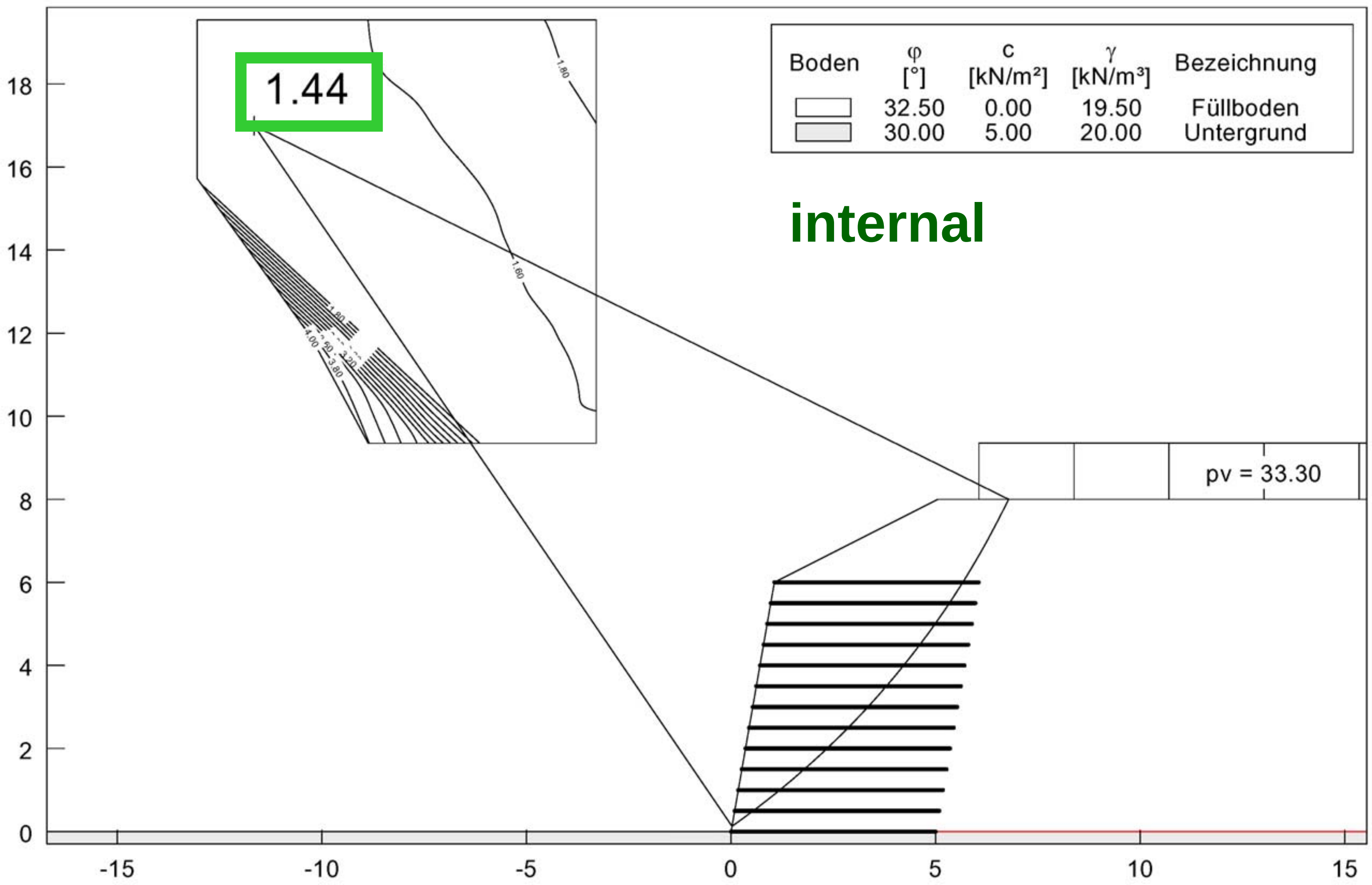
Modi of failure to be checked



The <u>min</u> value is decisive. Both strength and interaction are important.



Pay attention! …Compound…



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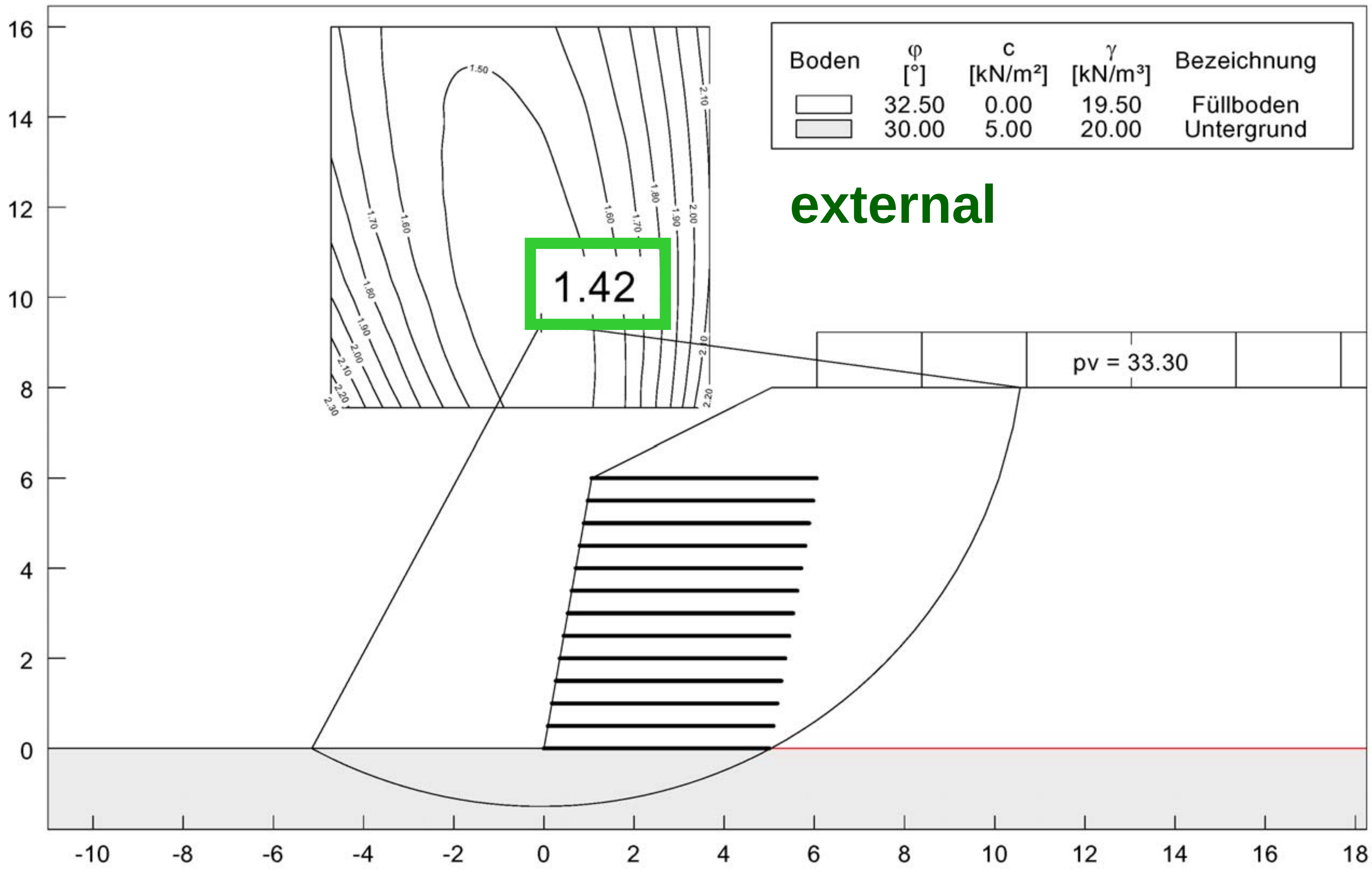
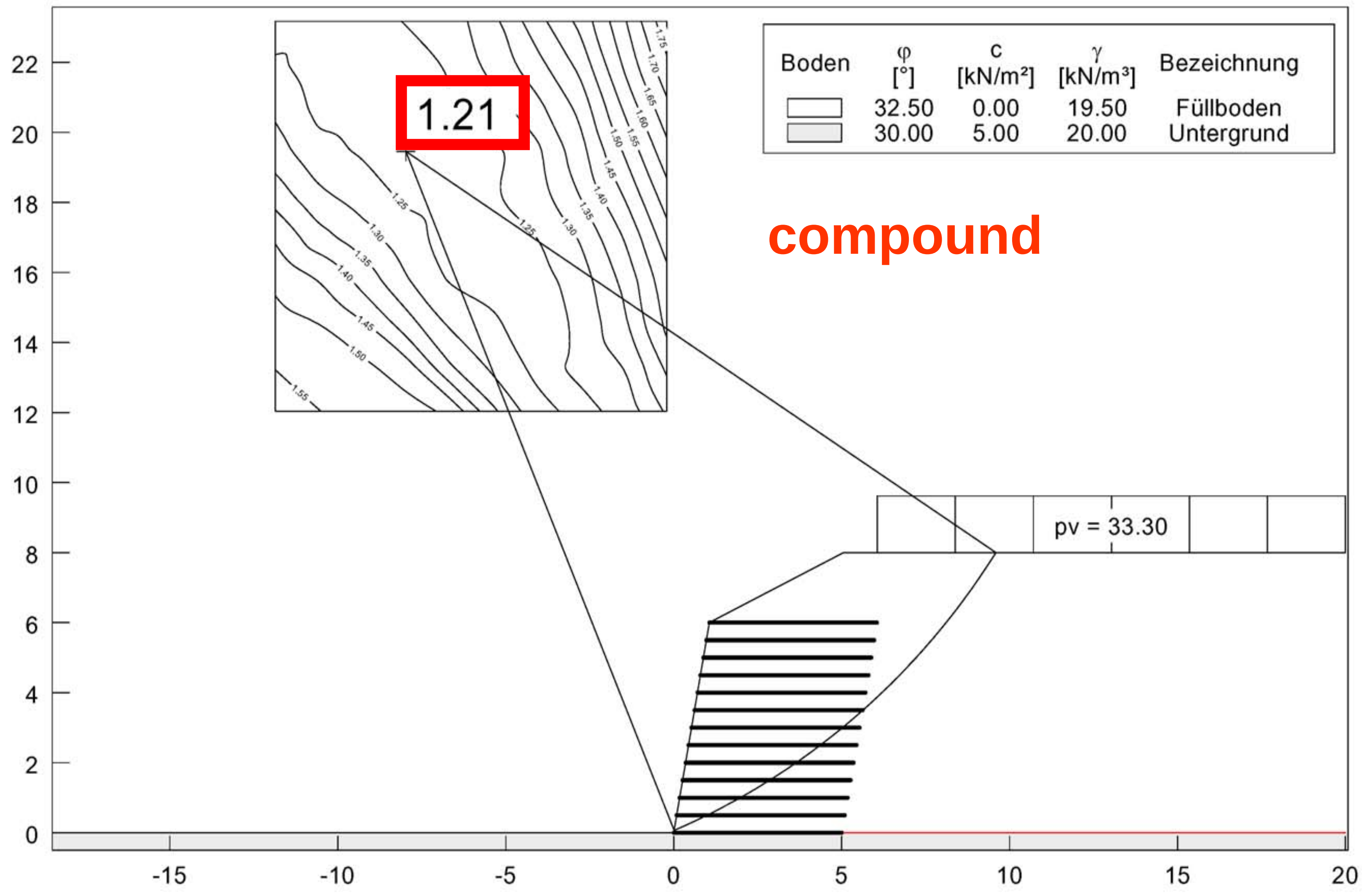
Pay attention! …Compound…



Pay attention! …Compound…



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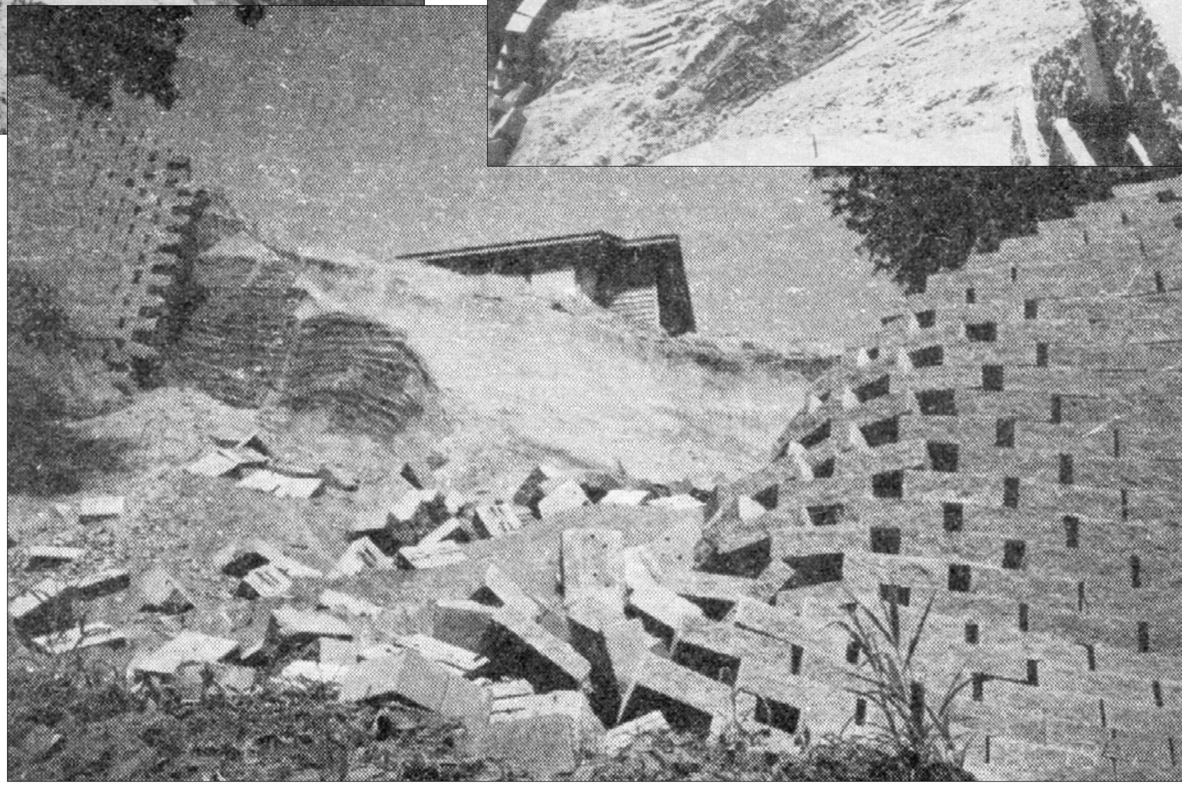
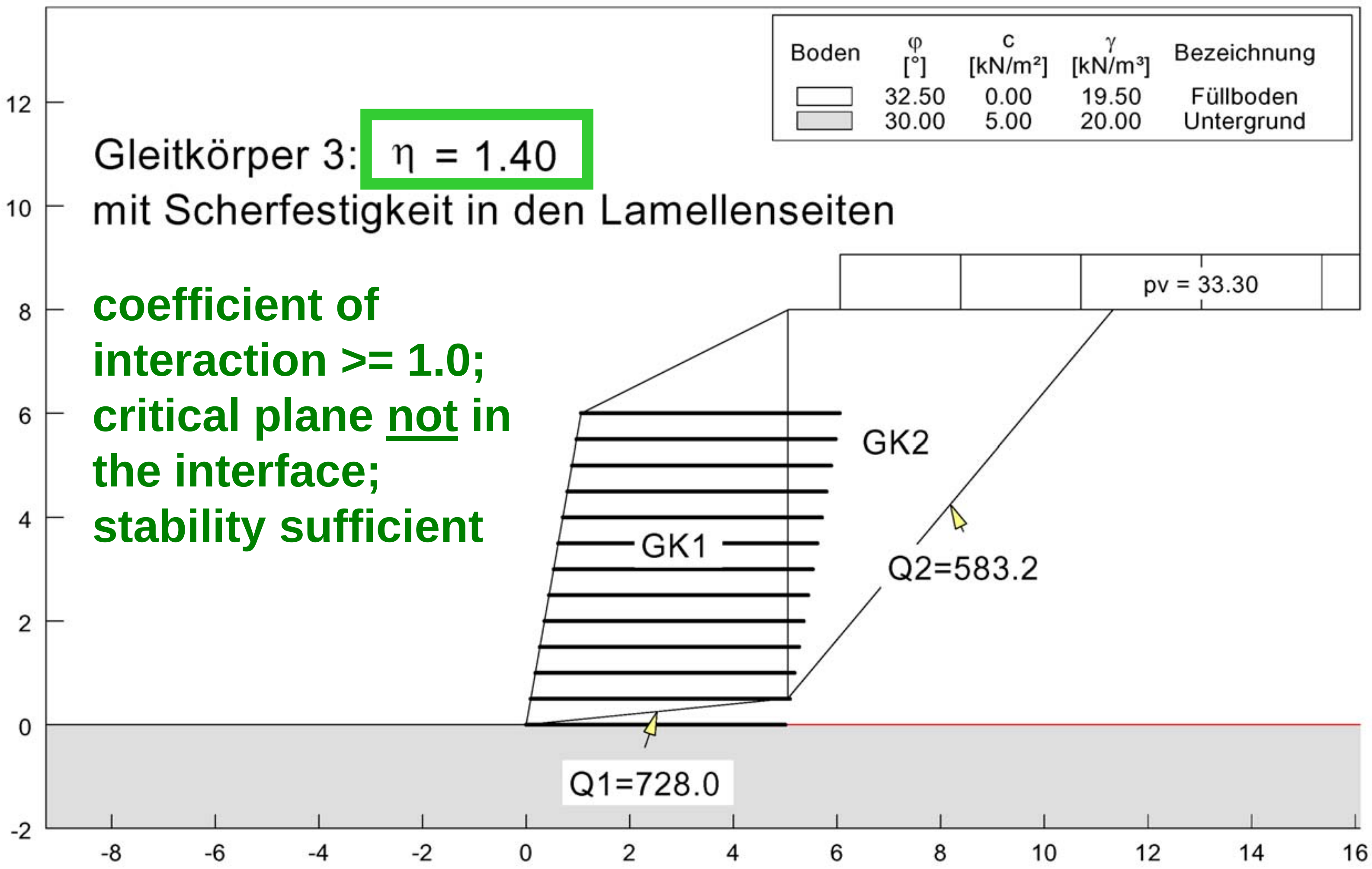
…Compound…

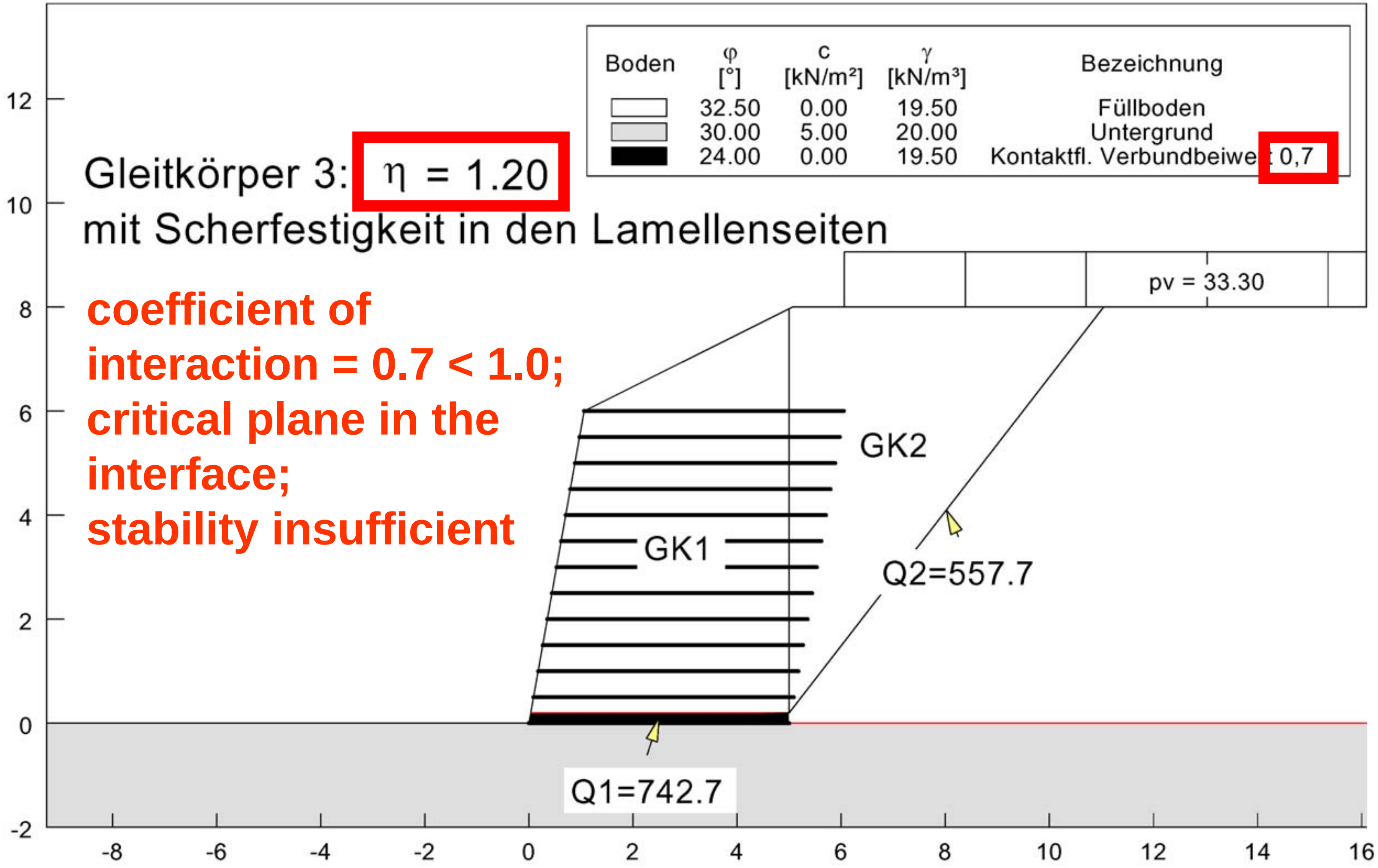


...Compound...

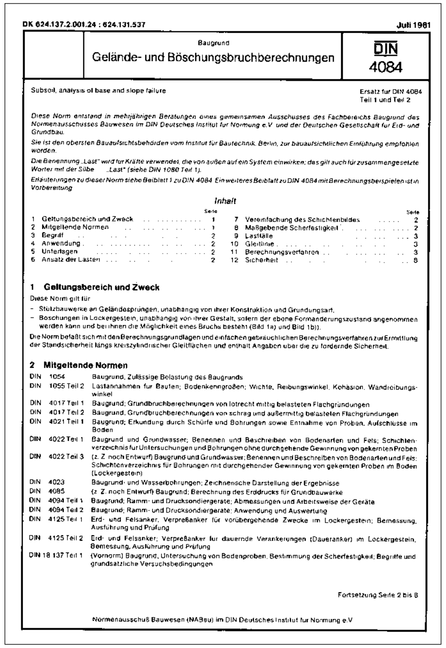
Interface sliding (shear); coefficients of interaction



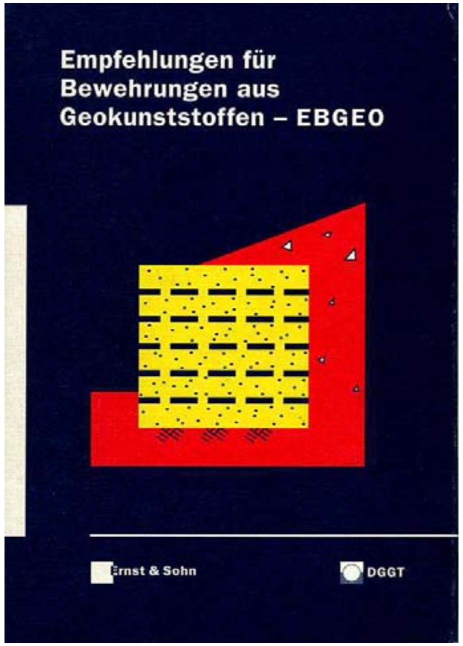
Interface sliding (shear); coefficients of interaction



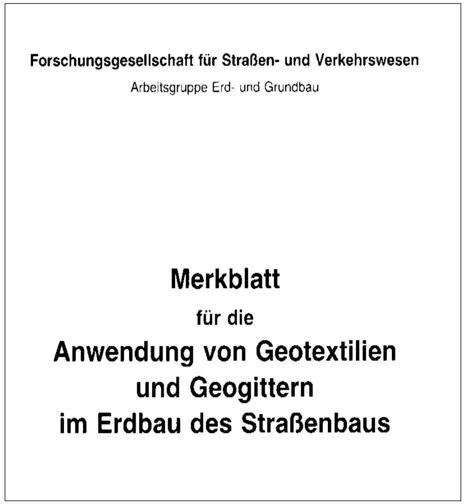
Basics & details: German documents



DIN 4084 and 1054: Basics of geotechnical stability calculations and **safety factors**: Bishop, Janbu etc.



EBGEO (new to come in 2007): Geosynthetic reinforcement & stability calculations



German Road Administaration: General recommendations for the functions of geosynthetics in geotechnical structures for roads

DB (German Rail): Geosynthetic regulations

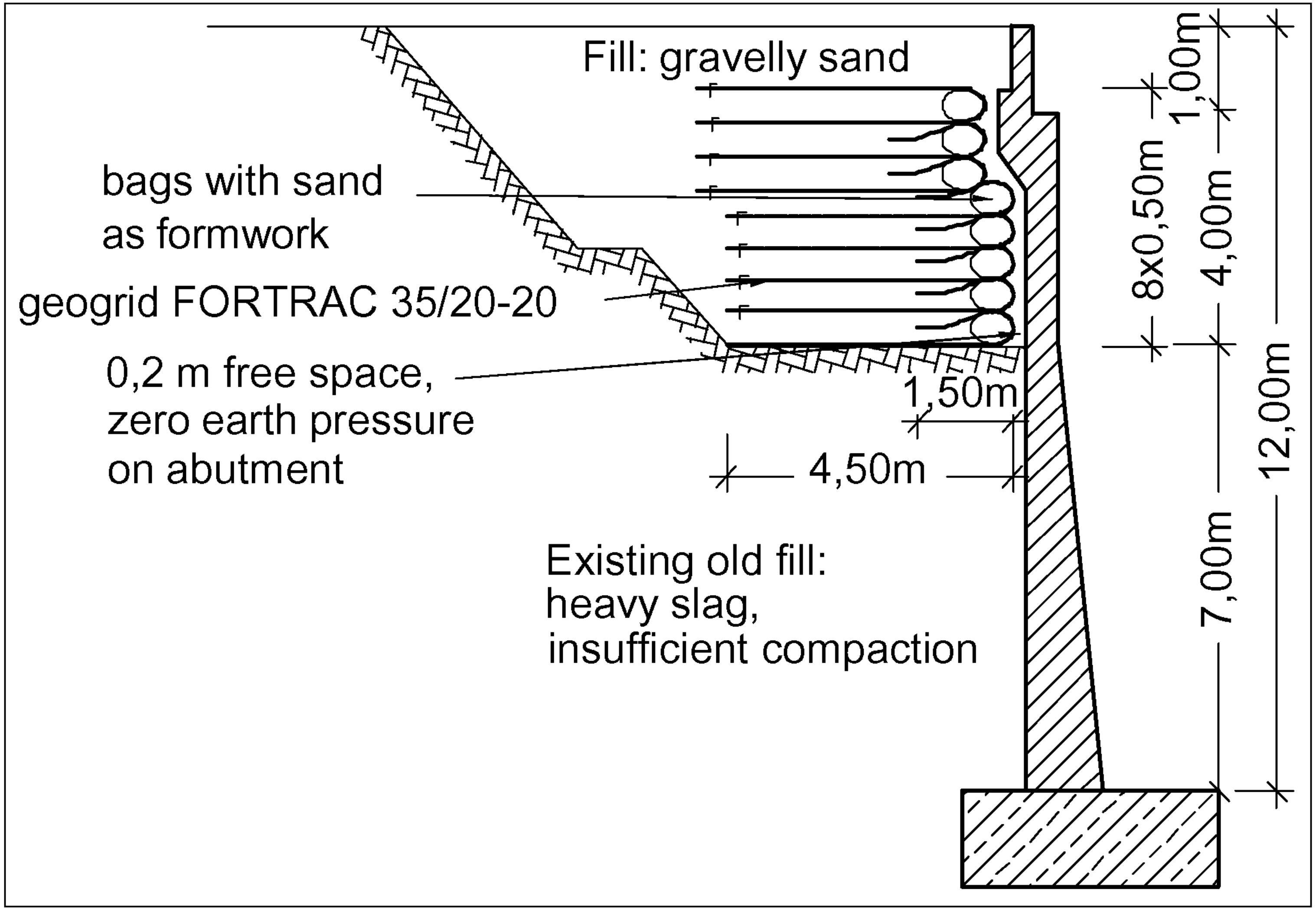
Note: the design and calculation procedures for bridge abutments are generally the same as for slopes/walls.

Two specific points:

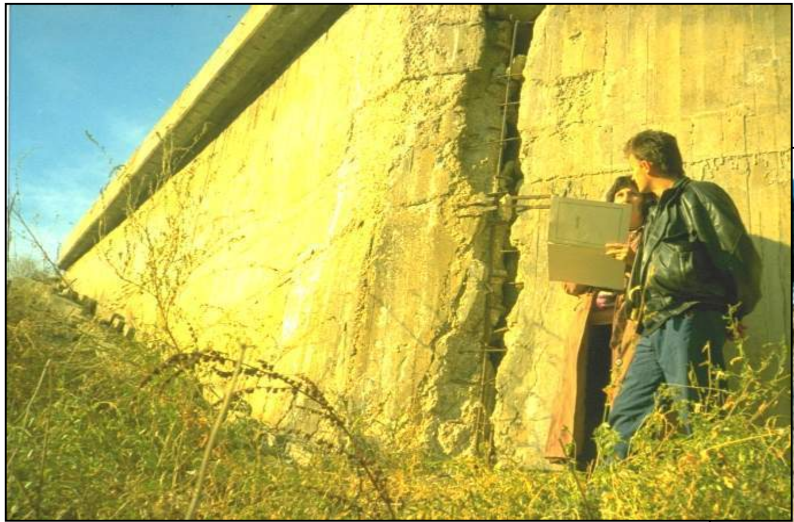
1. **High strip load near the edge of the abutment (usually 150 to 250 kPa).**
2. **More rigid limitation of deformations, e.g. 1.0 or 0.5 % post-construction strain in reinforcement only.**
3. **See projects below and especially the abutment tests at the LGA Nuremberg.**

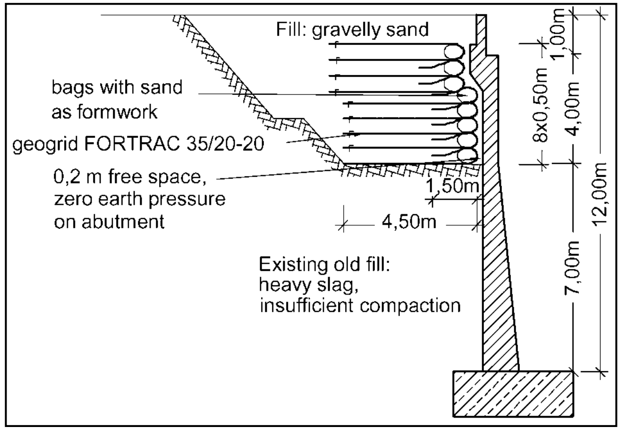
Some interesting projects

Bridge Abutments Repair, Motorway Hemus, Bulgaria, 1997



Bridge Abutments Repair, Motorway Hemus, Bulgaria, 1997





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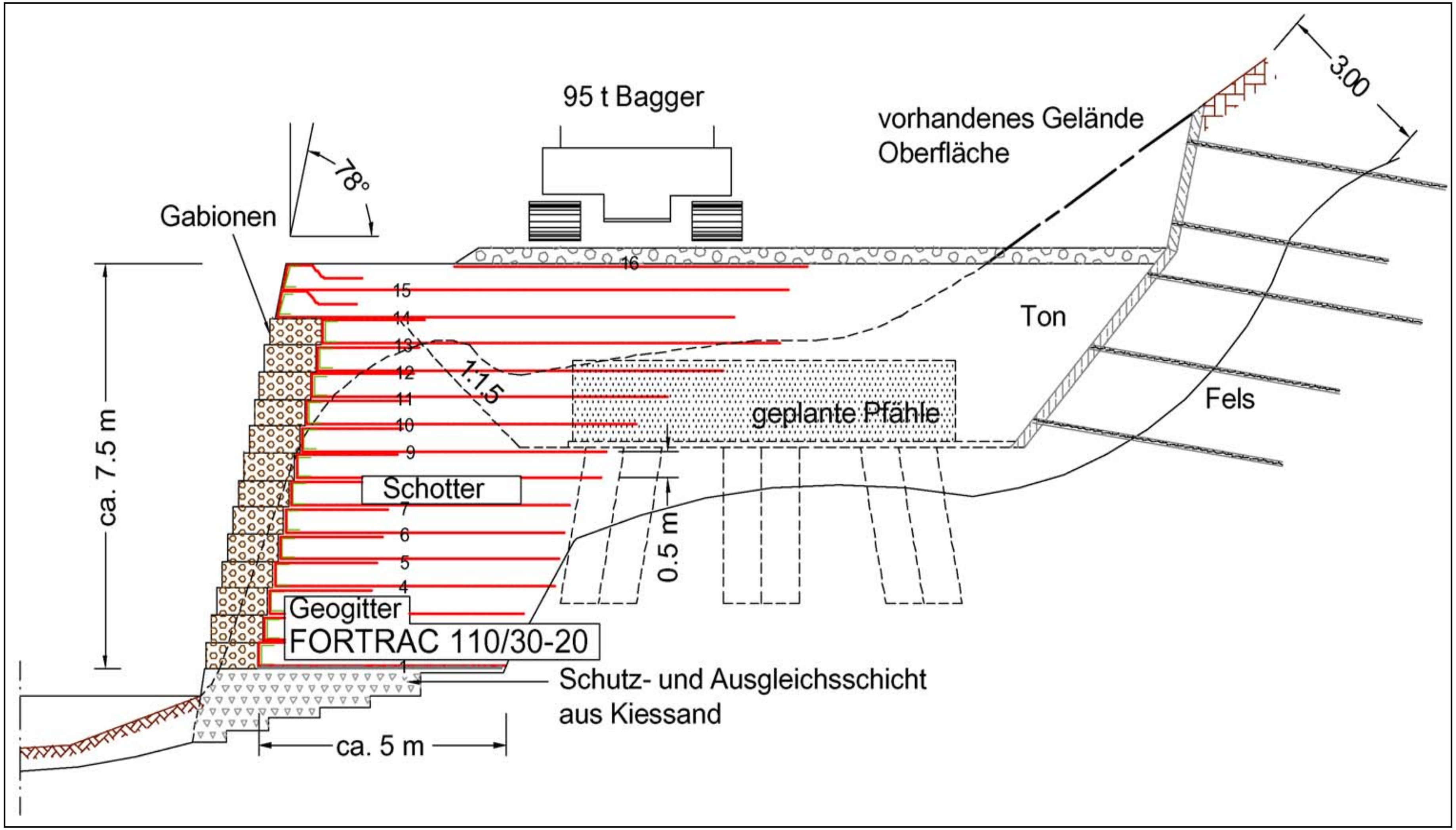
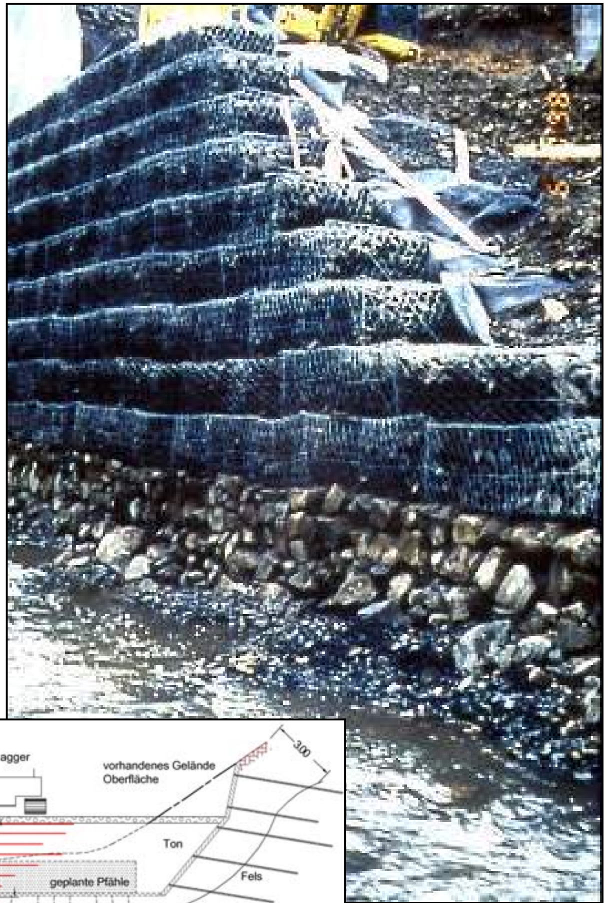
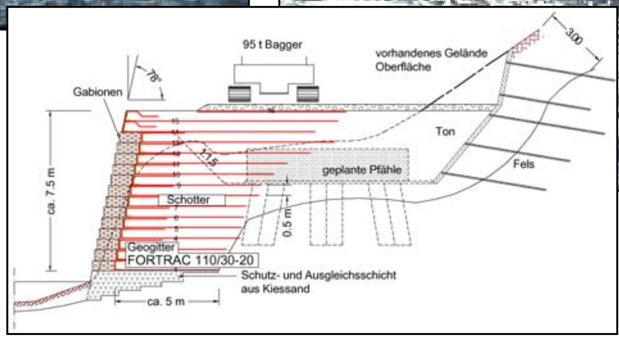
Bridge Abutment Hallerbach Bridge, Germany, 1998

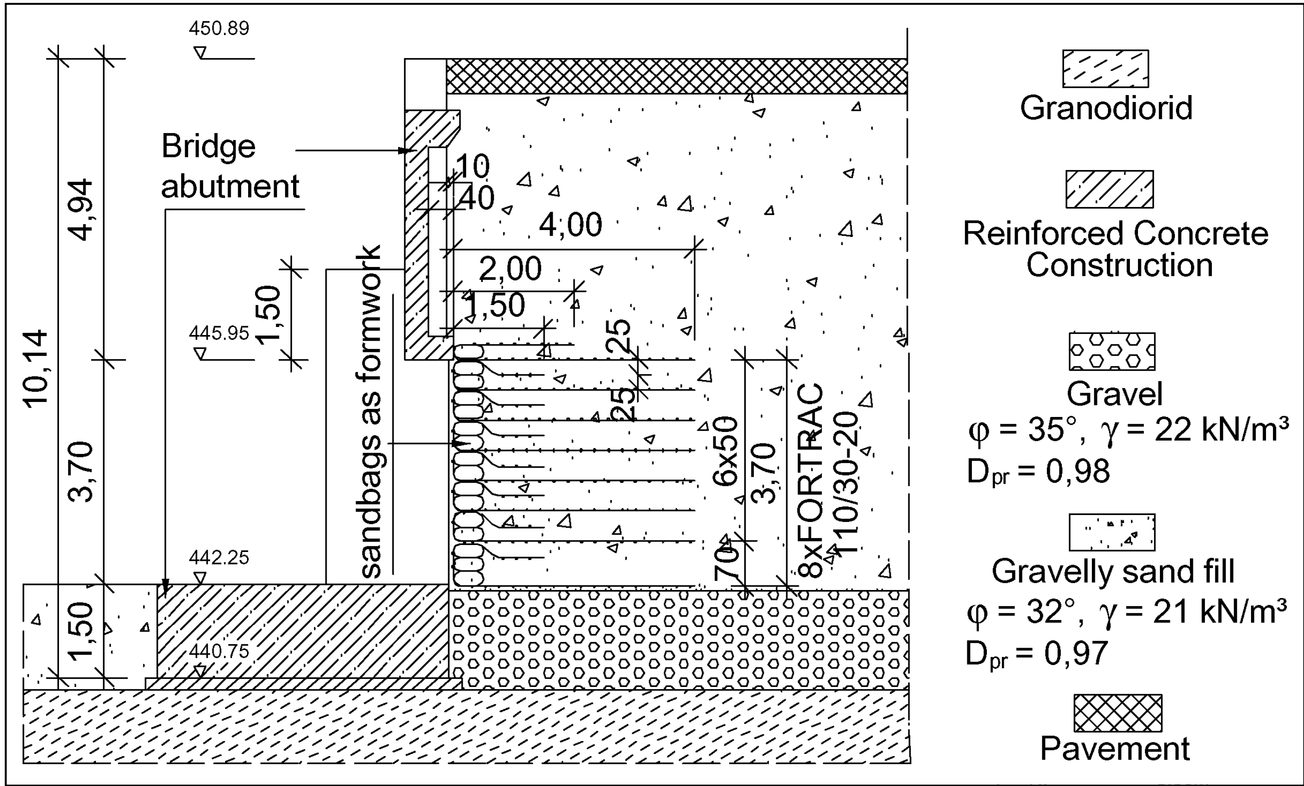


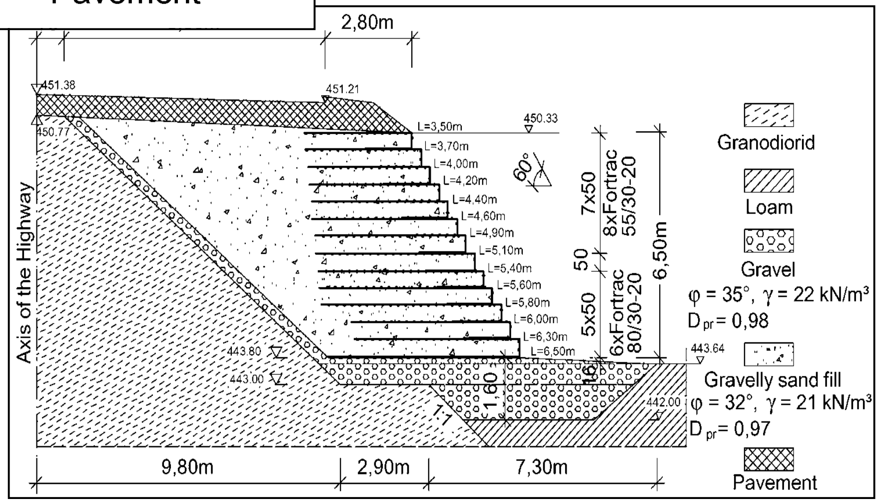
Bridge Abutment Hallerbach Bridge, Germany, 1998





Autobahn Hemus, Bulgaria: Abutment and Slope, 1998





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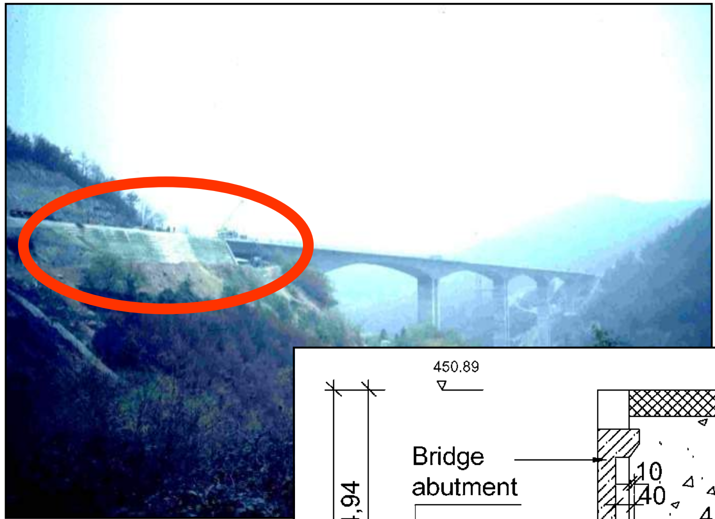
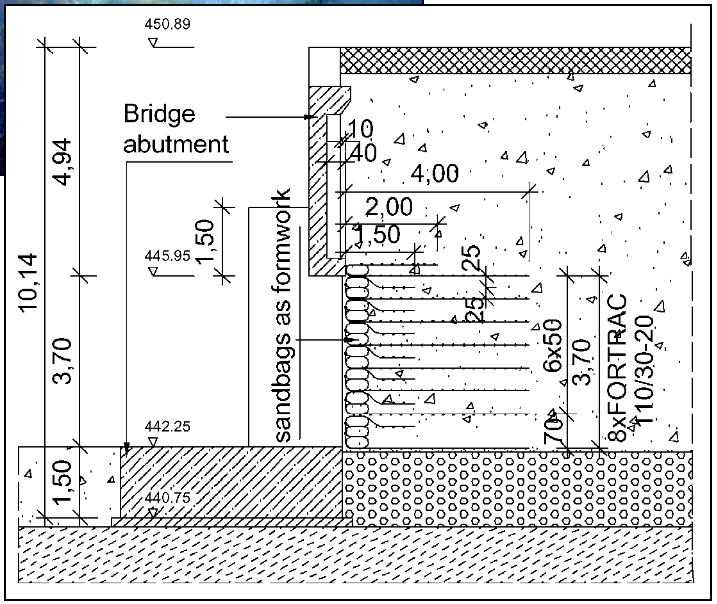
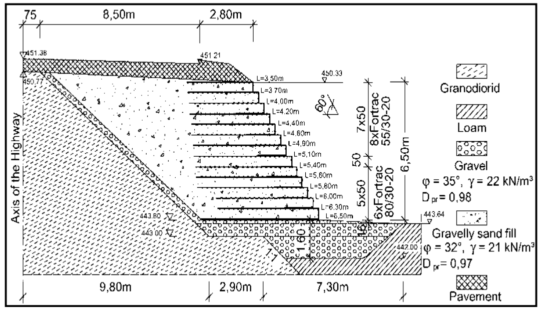
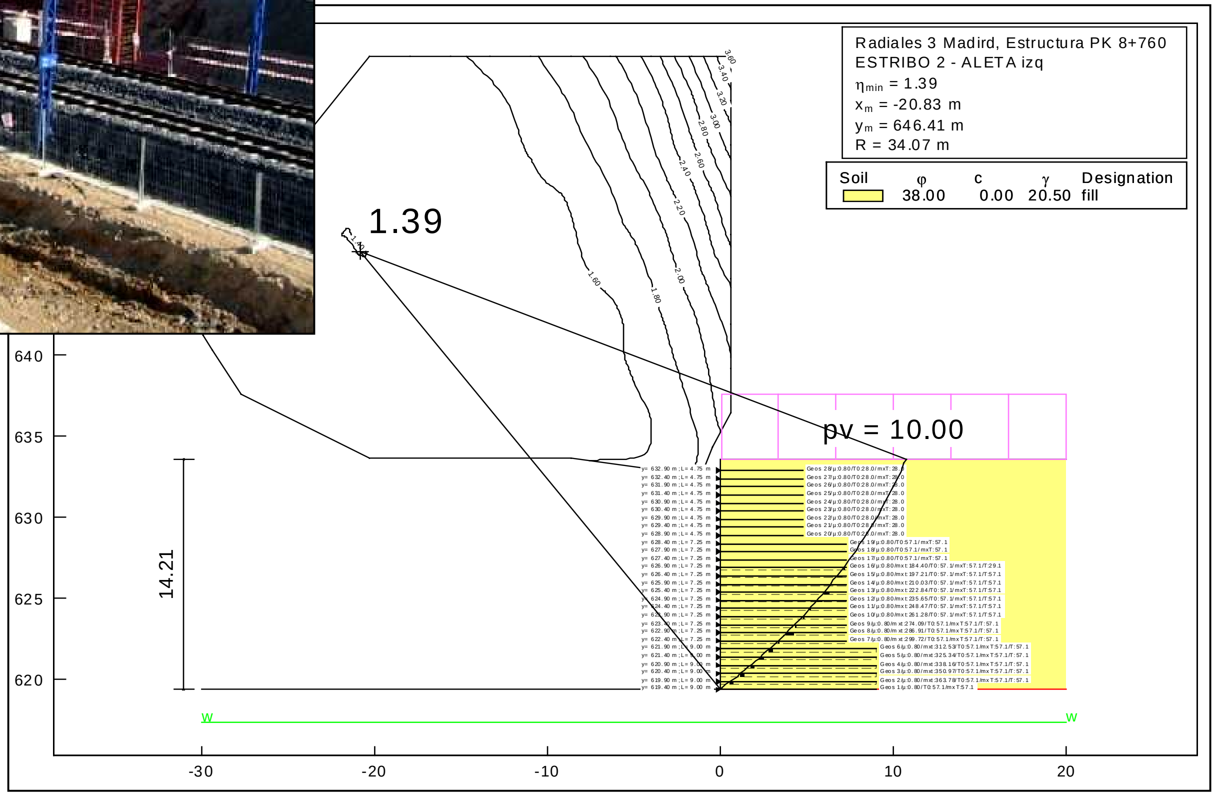
Autobahn Hemus, Bulgaria: Abutment and Slope, 1998



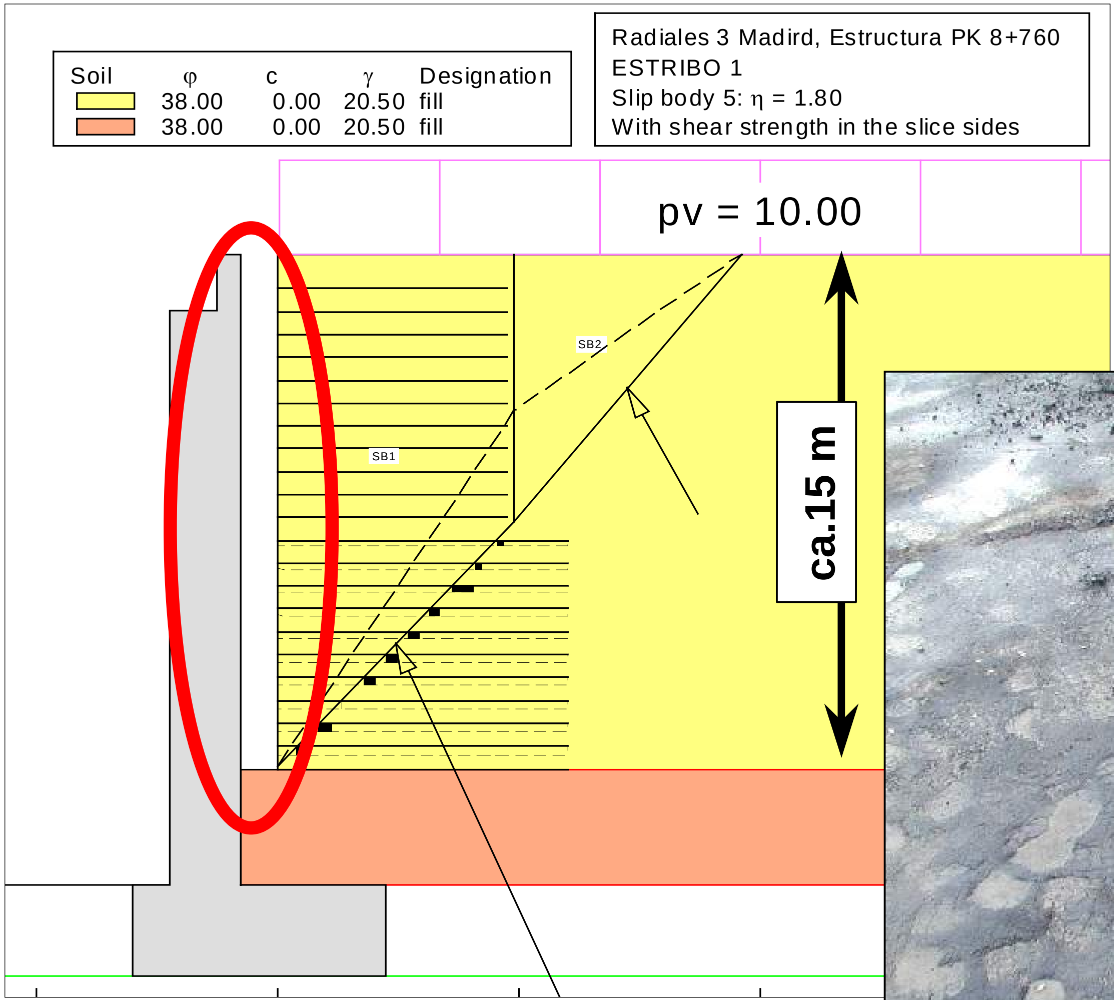




Bridge abutment front wall at Radiales 3, Madrid, Spain, 2003, H up to 15 m



Bridge abutment front wall at Radiales 3, Madrid, Spain, 2003, H up to 15 m



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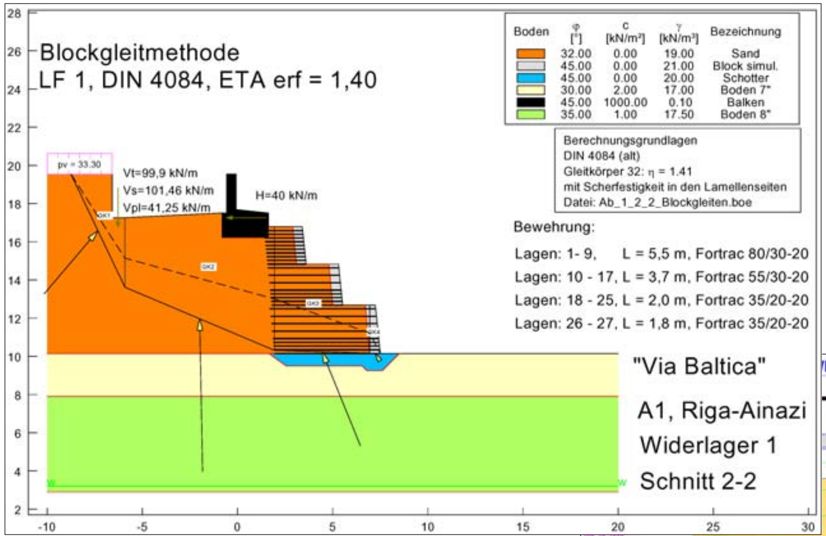
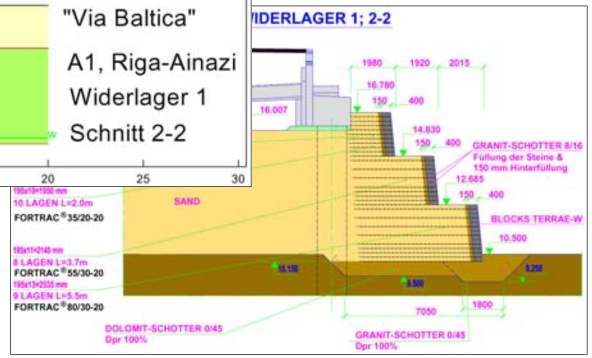
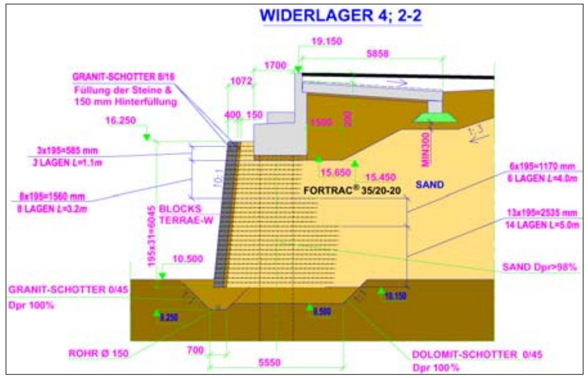
Riga, Via Baltica, 2003-2004







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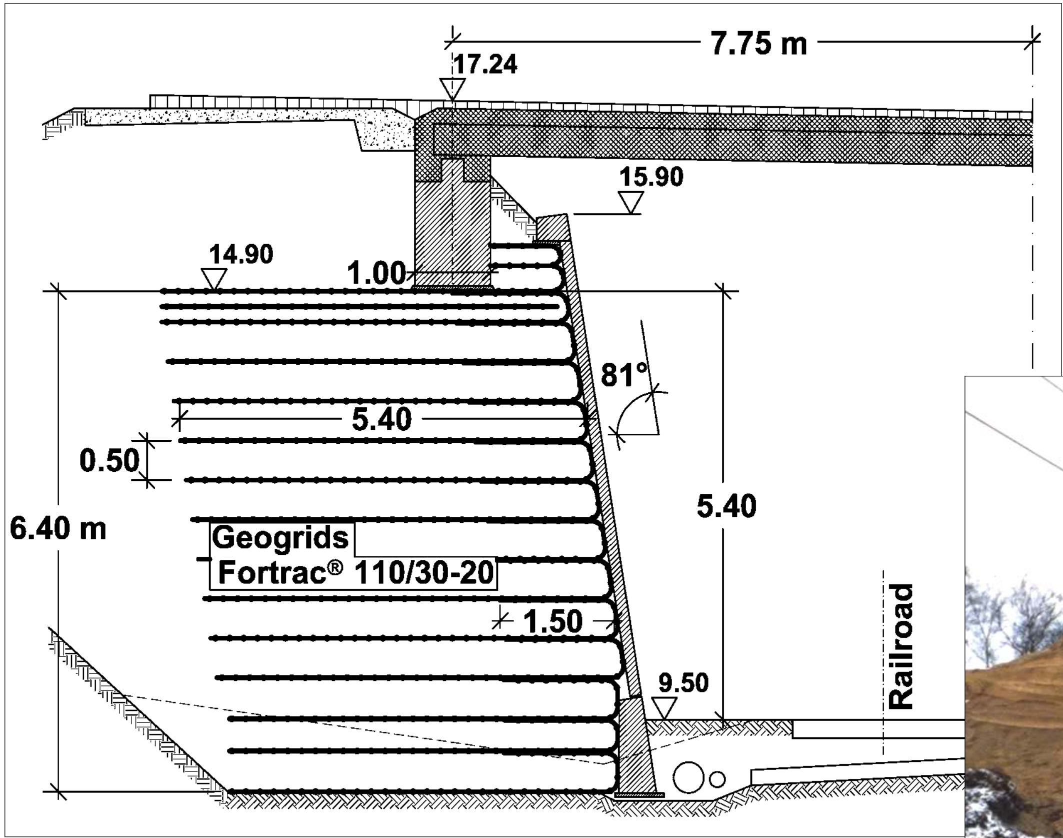
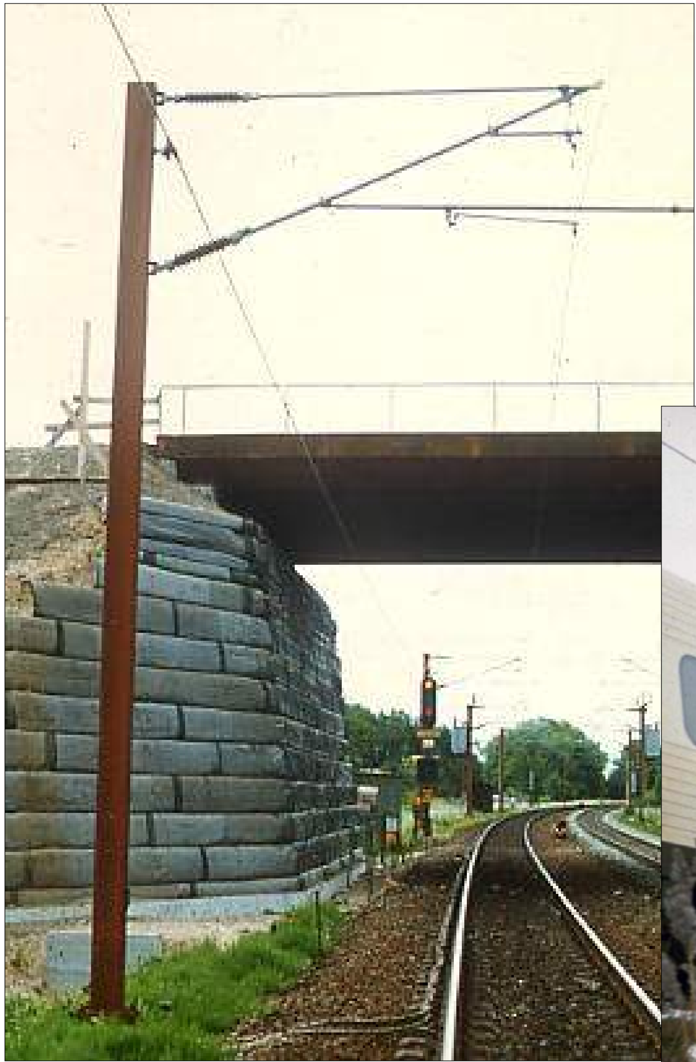


Bridge abutments at Ullerslev, Denmark, 1991
May be the first geogrid-reinforced bridge abutment in Europe



Bridge abutments at Ullerslev, Denmark, 1991
May be the first geogrid-reinforced bridge abutment in Europe

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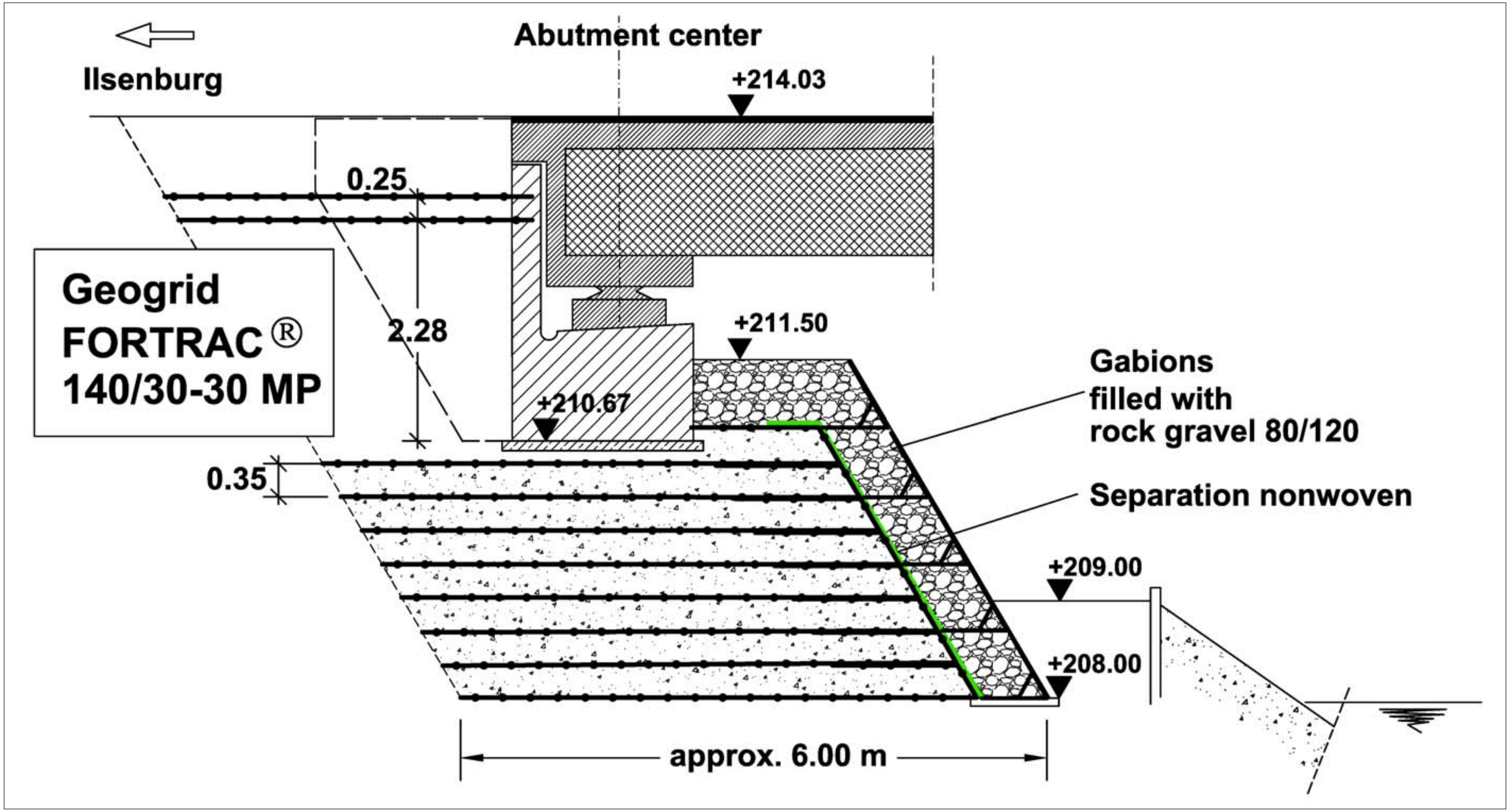
Bridge abutments River Ilse on Road K 1355: 1st permanent geogrid reinforced abutment in the German road net, 2002



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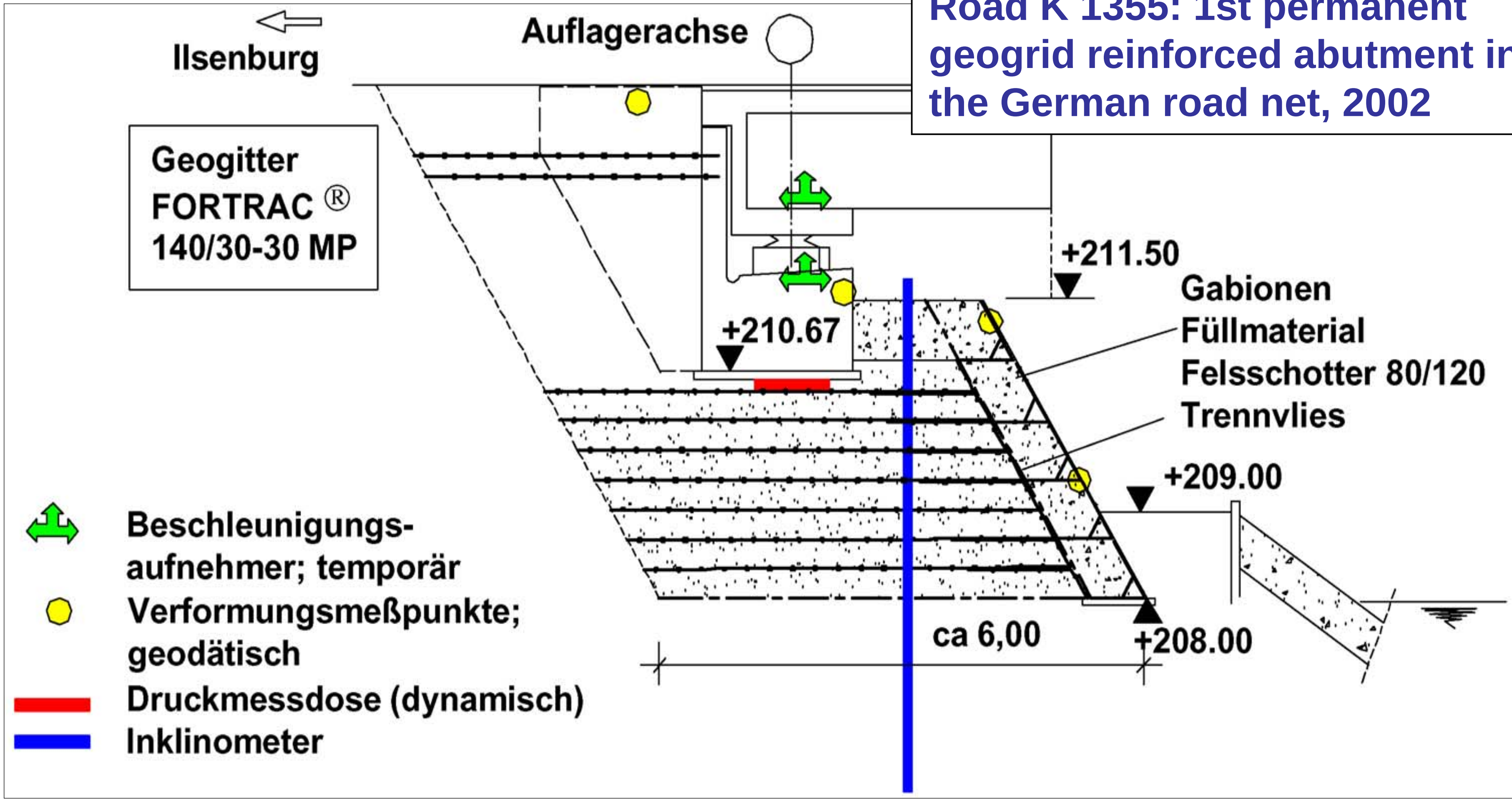

Measured deformations until now in the range of some mm.

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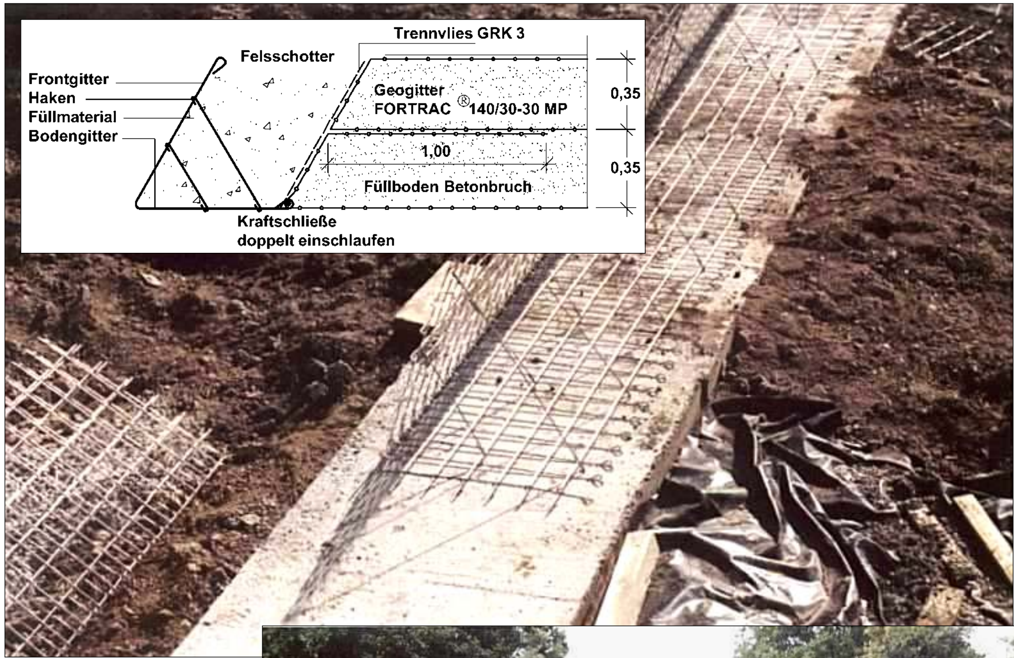

Bridge abutments River Ilse on Road K 1355: 1st permanent geogrid reinforced abutment in the German road net, 2002

Bridge abutments River Ilse on Road K 1355: 1st permanent geogrid reinforced abutment in the German road net, 2002

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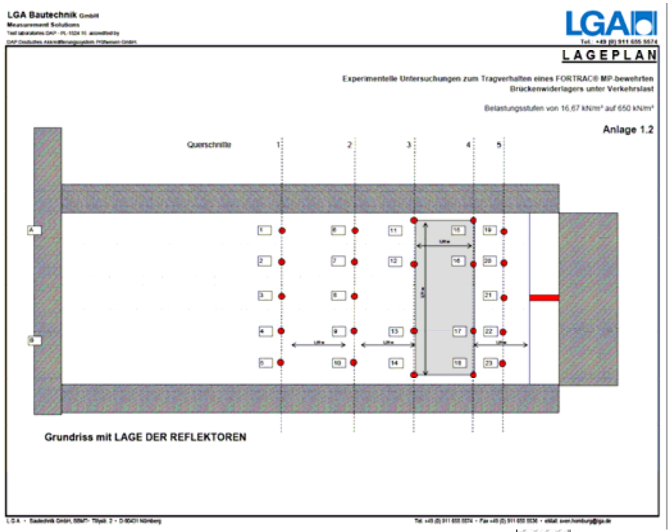
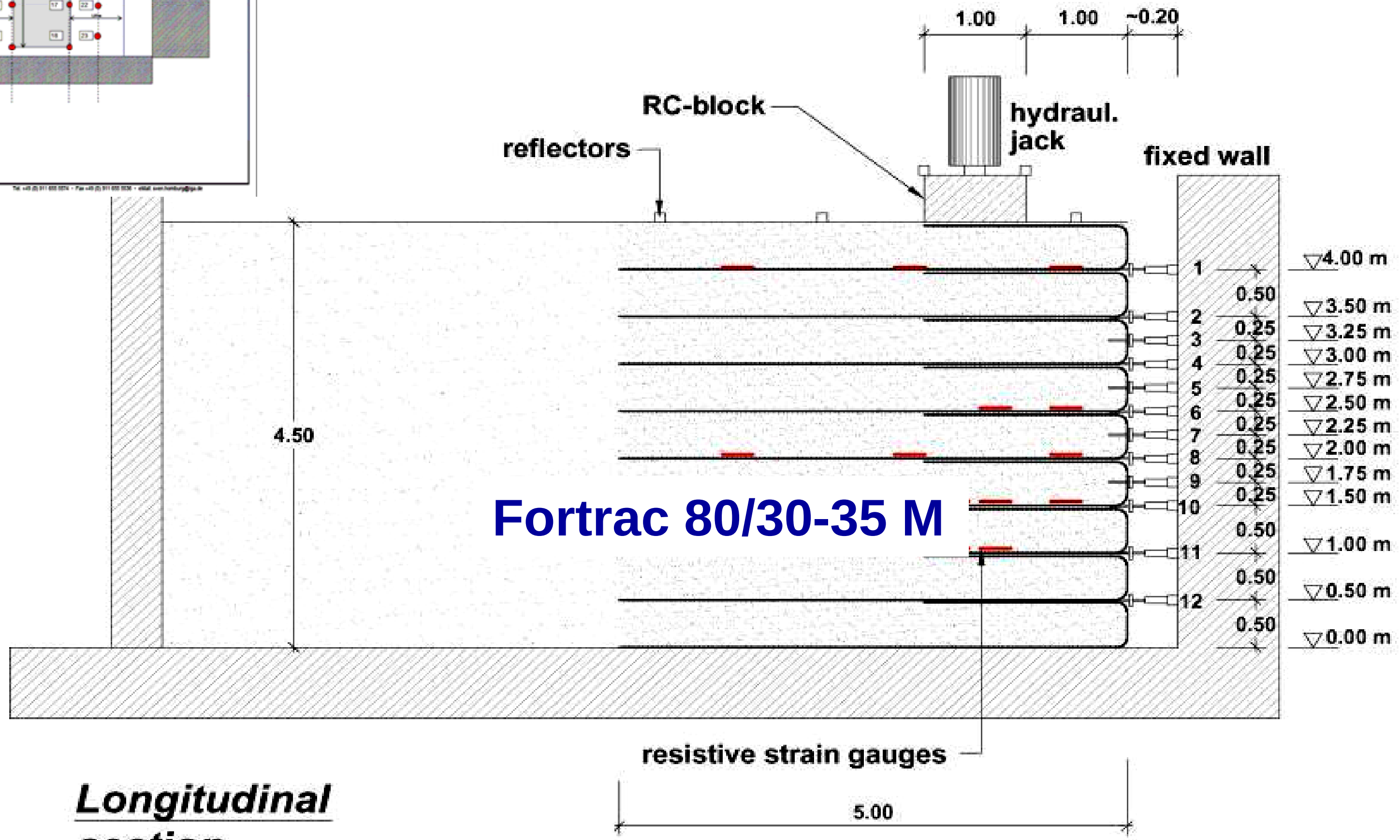
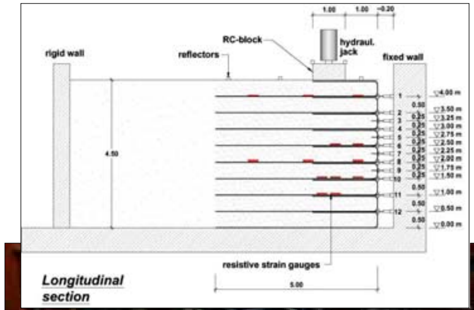
HUESKER Bridge abutment test LGA Nuremberg, 2006

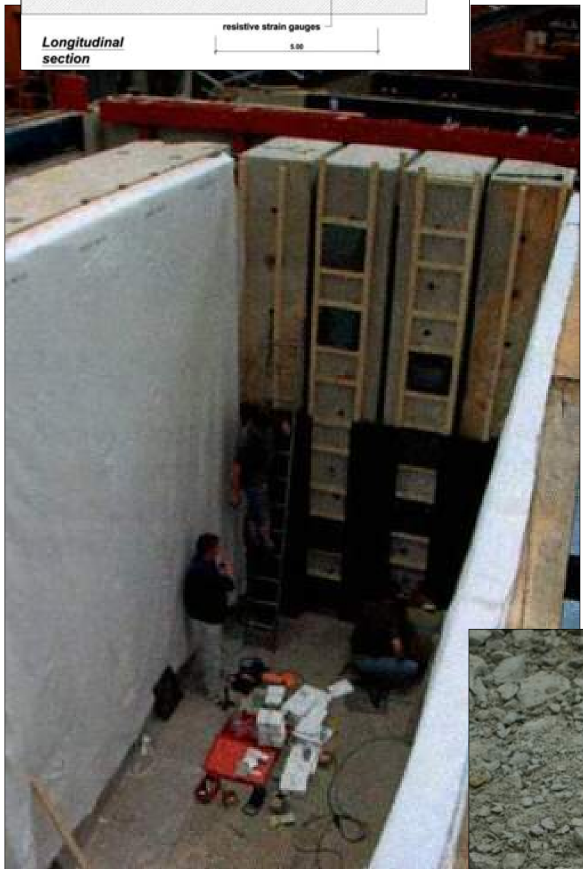




Longitudinal section

HUESKER Bridge abutment test
LGA Nuremberg, 2006





HUESKER Bridge abutment test
LGA Nuremberg, 2006

- **Worst case conditions:**
- **Soft facing (simply wrapped-back)**
- **Dpr = 95% (instead of 98% to 100%) in the upper most critical part of wall**
- **Note: the wall was built without our supervision…**
- **Loaded by a quite narrow RC-block (1 m instead of usually 1.3 to 1.5 m)**
- **Only 1 m from the edge (usually 1.2 to 1.5 m)**
- **Extreme load of up to 600 kN/m² as a goal (usually 120 to 150 kN/m²)**

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LGA Nuremberg, 2006

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LGA Nuremberg, 2006

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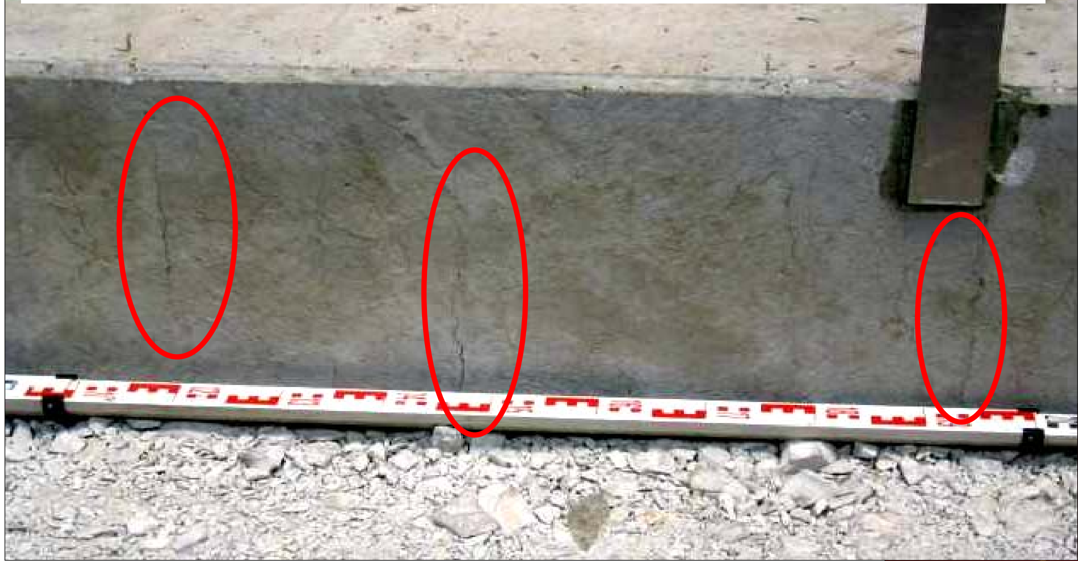
HUESKER Bridge abutment test LGA Nuremberg, 2006

Cracks in the RC-beam at 400 - 450 kN/m2



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HUESKER Bridge abutment test
LGA Nuremberg, 2006

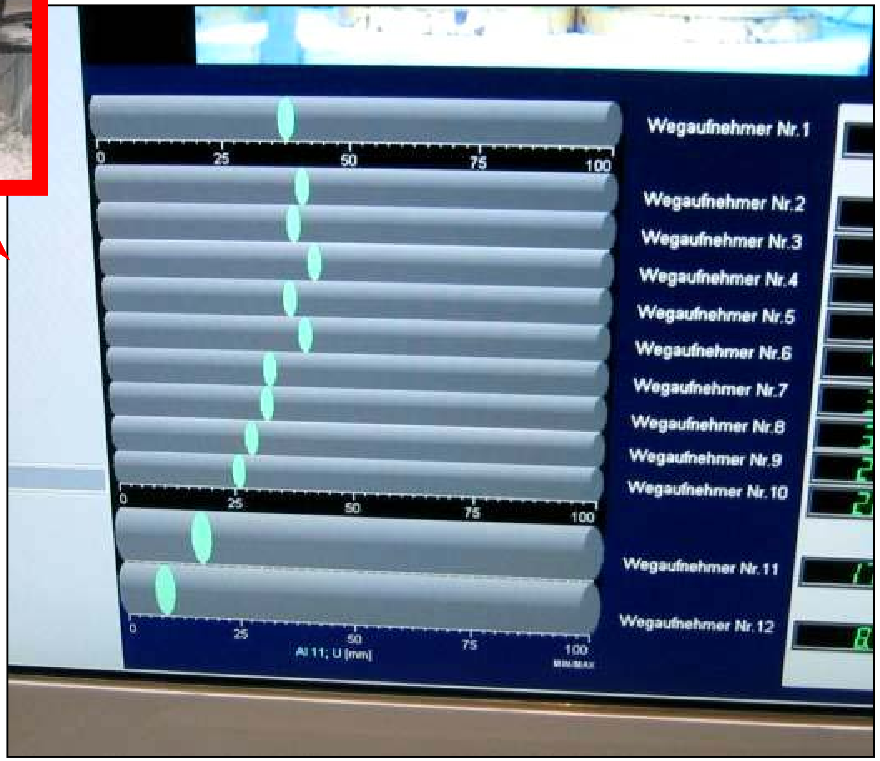
2000 X

600 kN/m²

tot 1580 kN on the block of 1.0 m x 2.7 m

more than 2 locomotives

or about 2 000 *average* civil engineers



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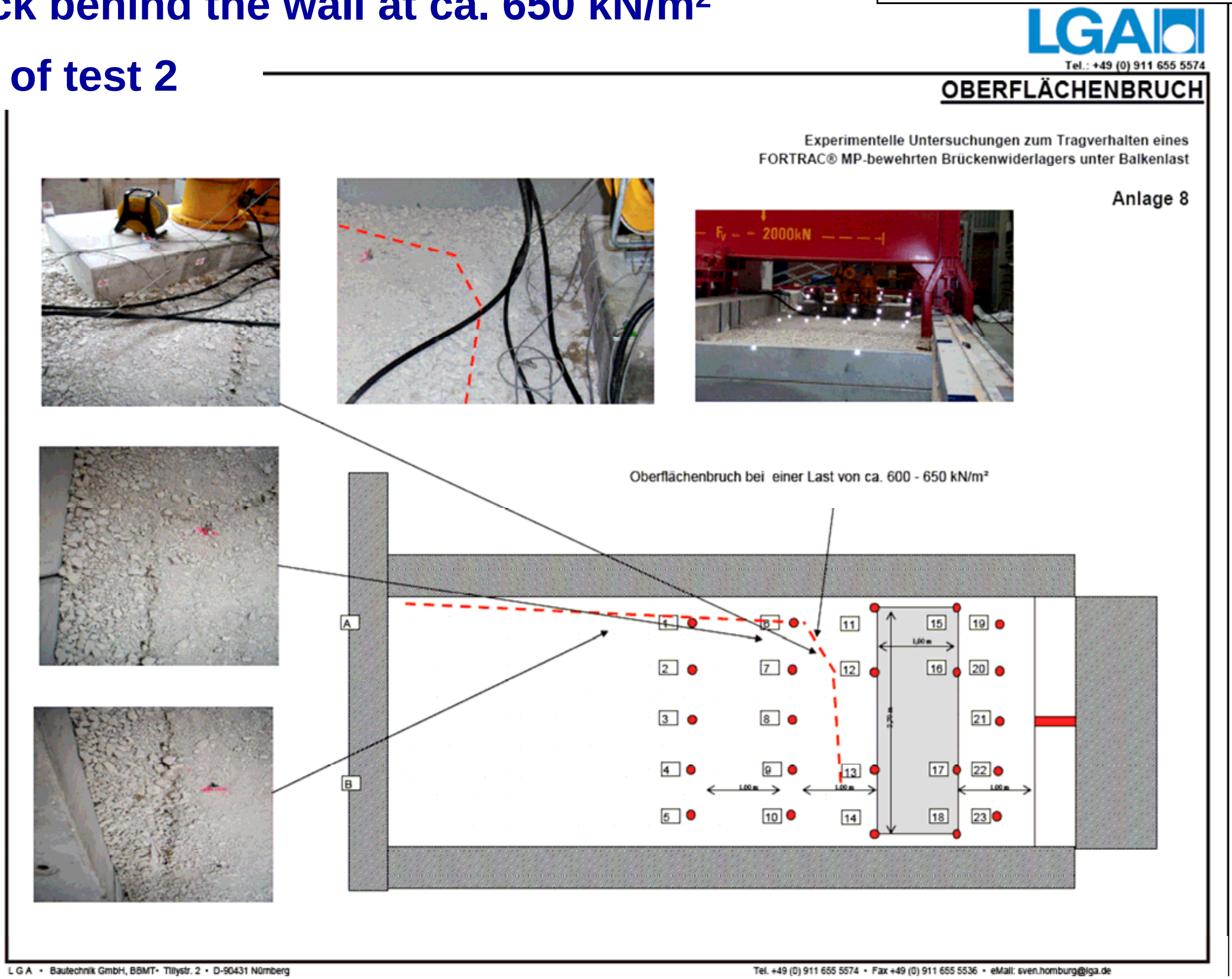
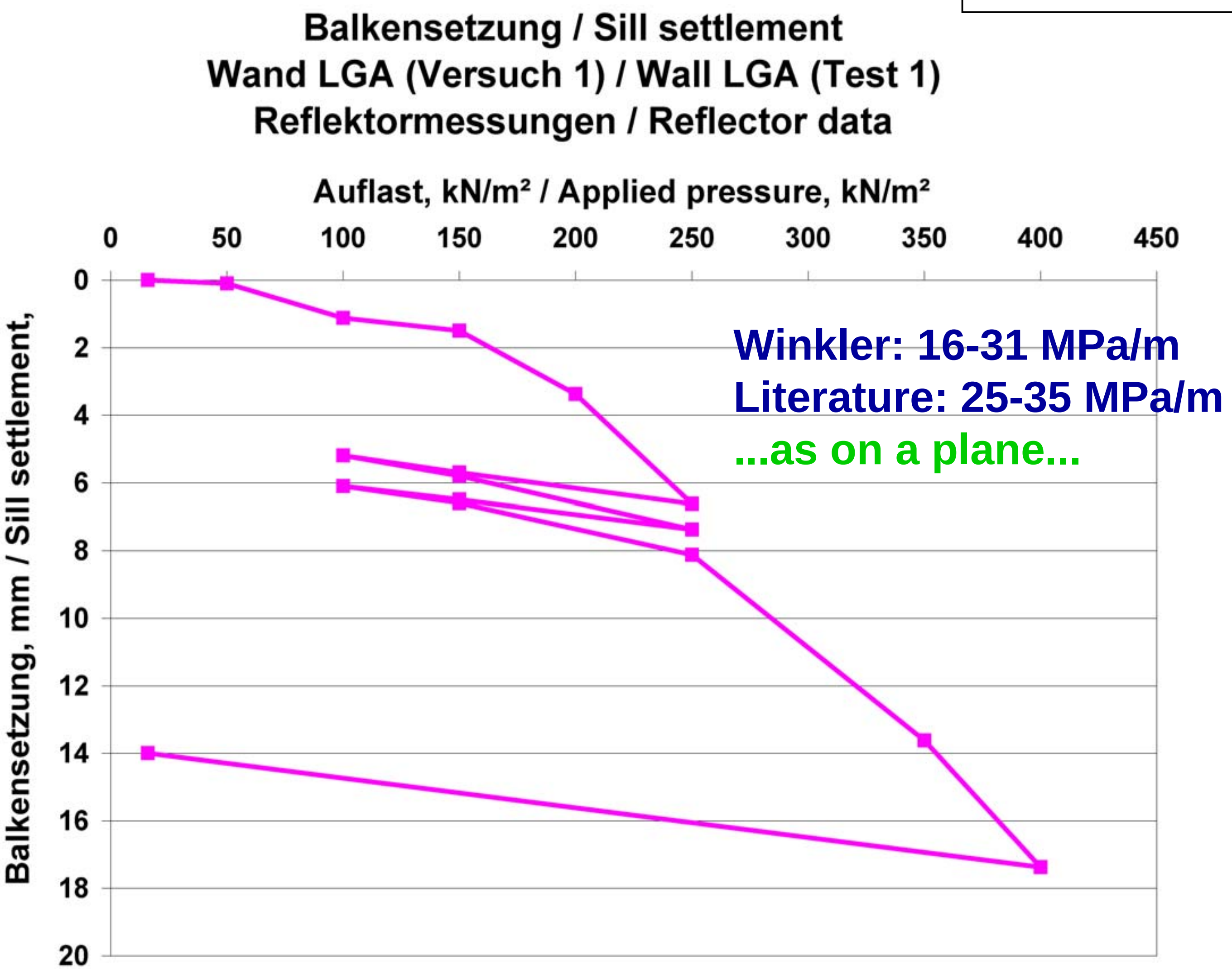
HUESKER Bridge abutment test
LGA Nuremberg, 2006

Crack behind the wall at ca. 650 kN/m²

End of test 2



HUESKER Bridge abutment test
LGA Nuremberg, 2006



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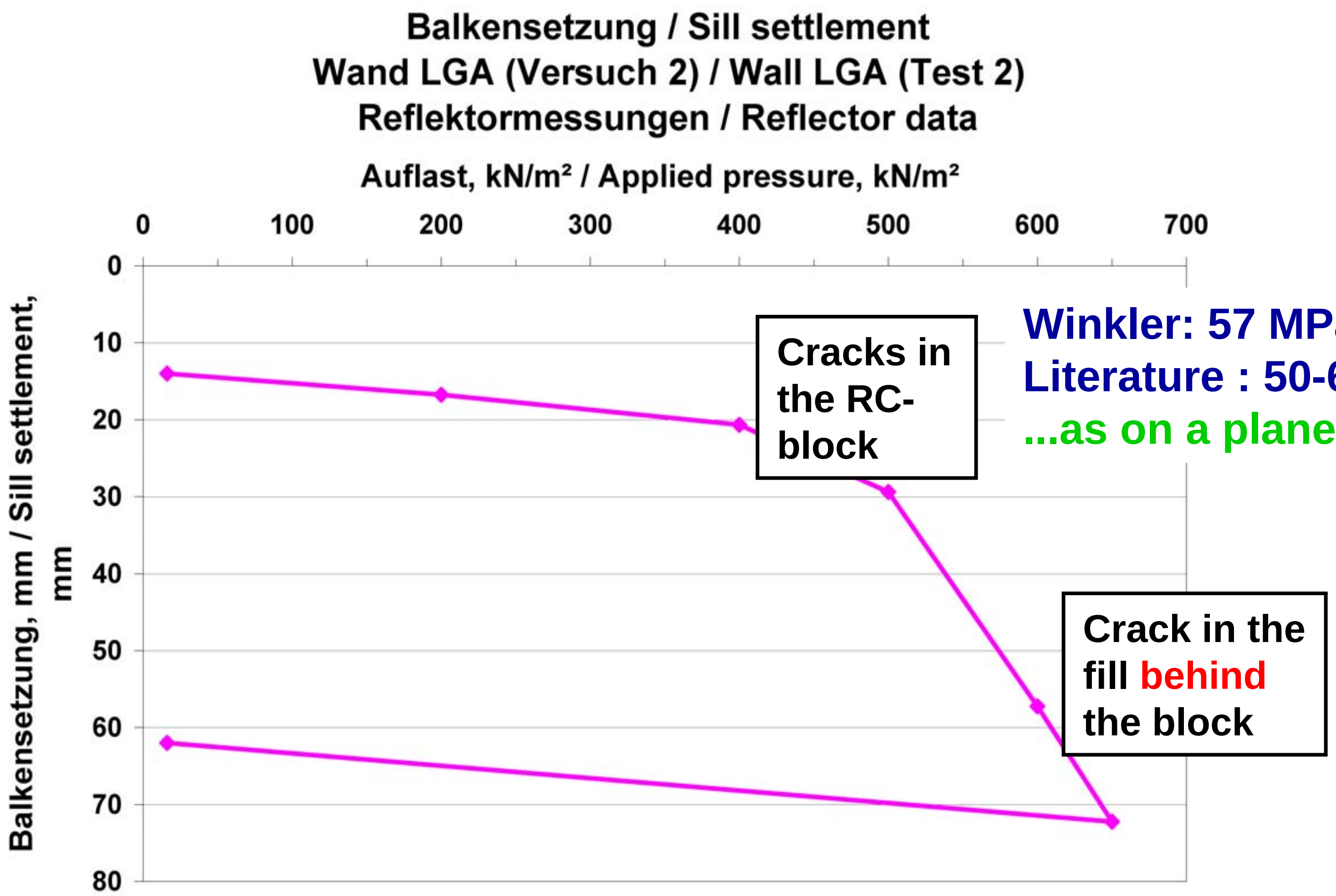
HUESKER Bridge abutment test
LGA Nuremberg, 2006



Winkler: 57 MPa/m
Literature : 50-60 MPa/m
...as on a plane...

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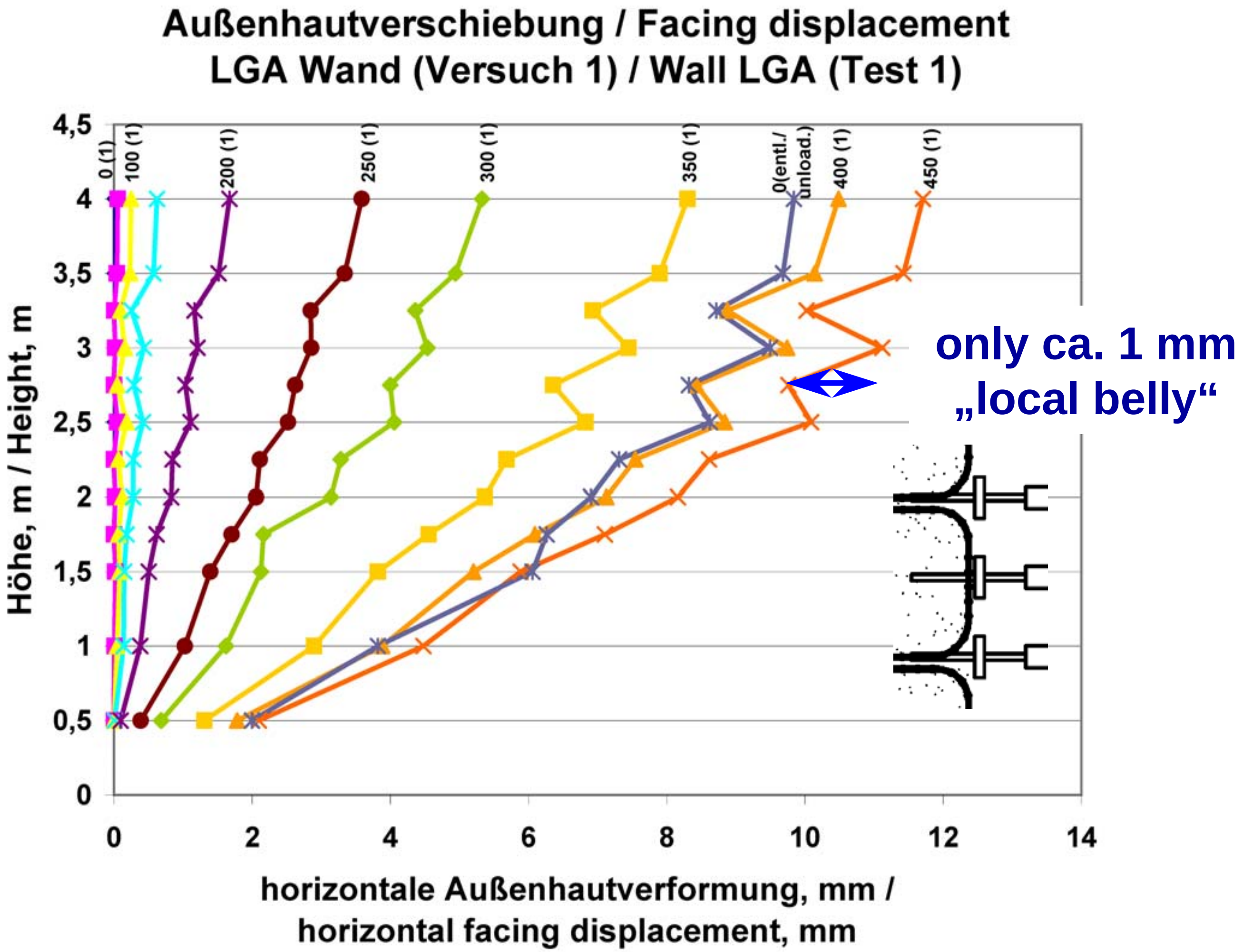
HUESKER Bridge abutment test
LGA Nuremberg, 2006



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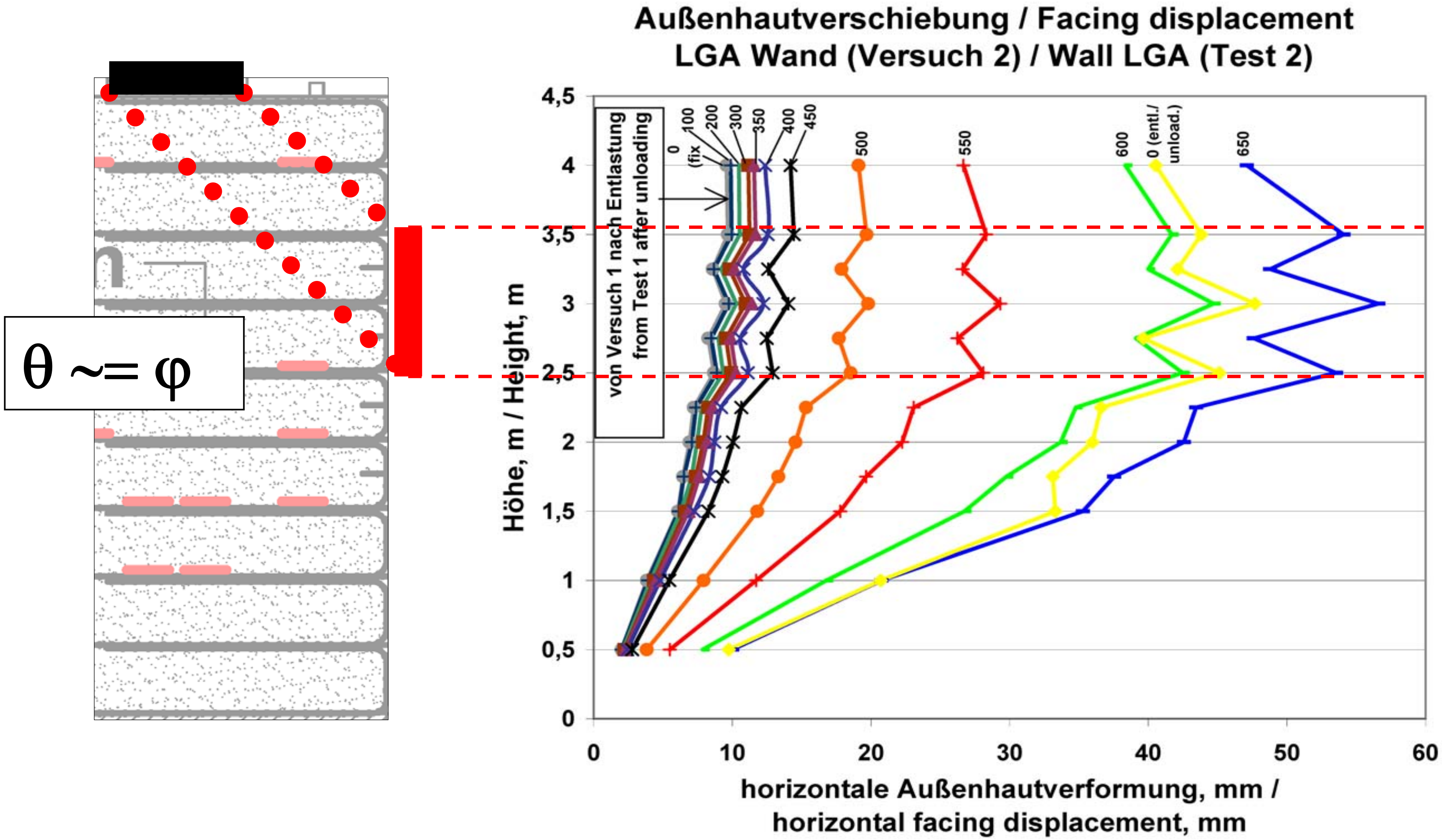
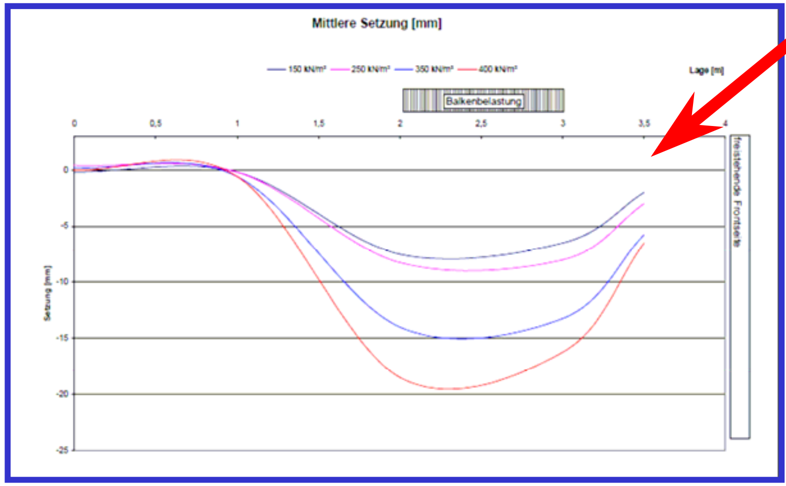
HUESKER Bridge abutment test
LGA Nuremberg, 2006

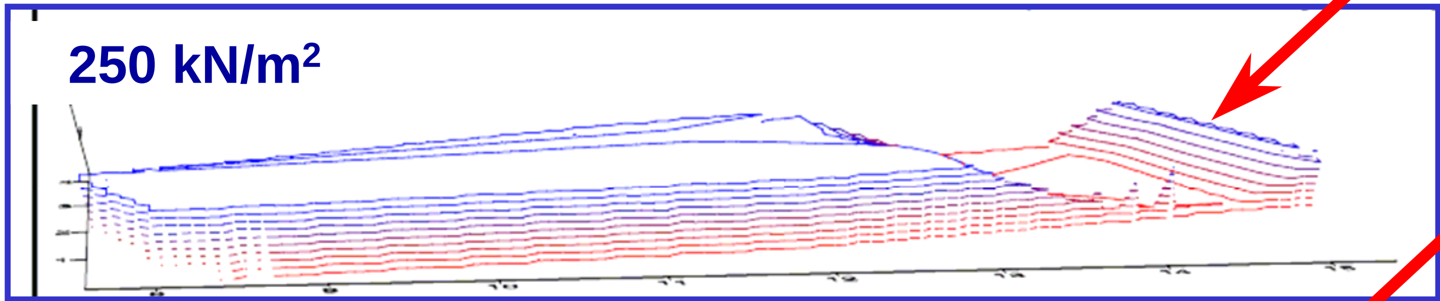


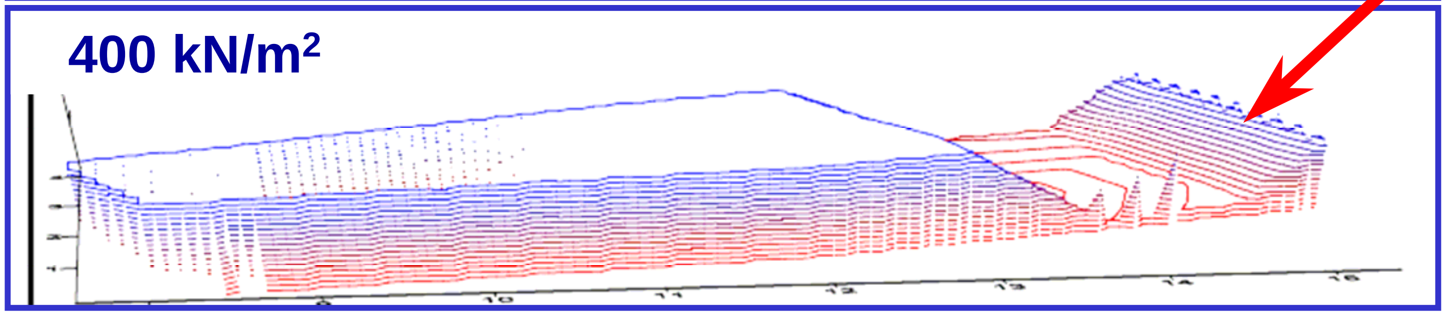
HUESKER

HUESKER Bridge abutment test
LGA Nuremberg, 2006



...as on a plane...





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HUESKER Bridge abutment test
LGA Nuremberg, 2006

Summary:

1. A pressure of up to 650 kN/m² (3x the common one) does not result into a component or system failure. Nevertheless, due to first indications it could be used as an ULS-benchmark.
2. A pressure of up to 400 kN/m² (2x the common one) results into only small, acceptable deformations.
3. The system tested demonstrates a technically friendly ductile behavior without any discontinuities.
4. The overall performance was good despite some soil compaction handicaps.
5. The wrapped-back facing from the flexible high-modular grids Fortrac 80/30-35 M experienced only low total and local deformations.

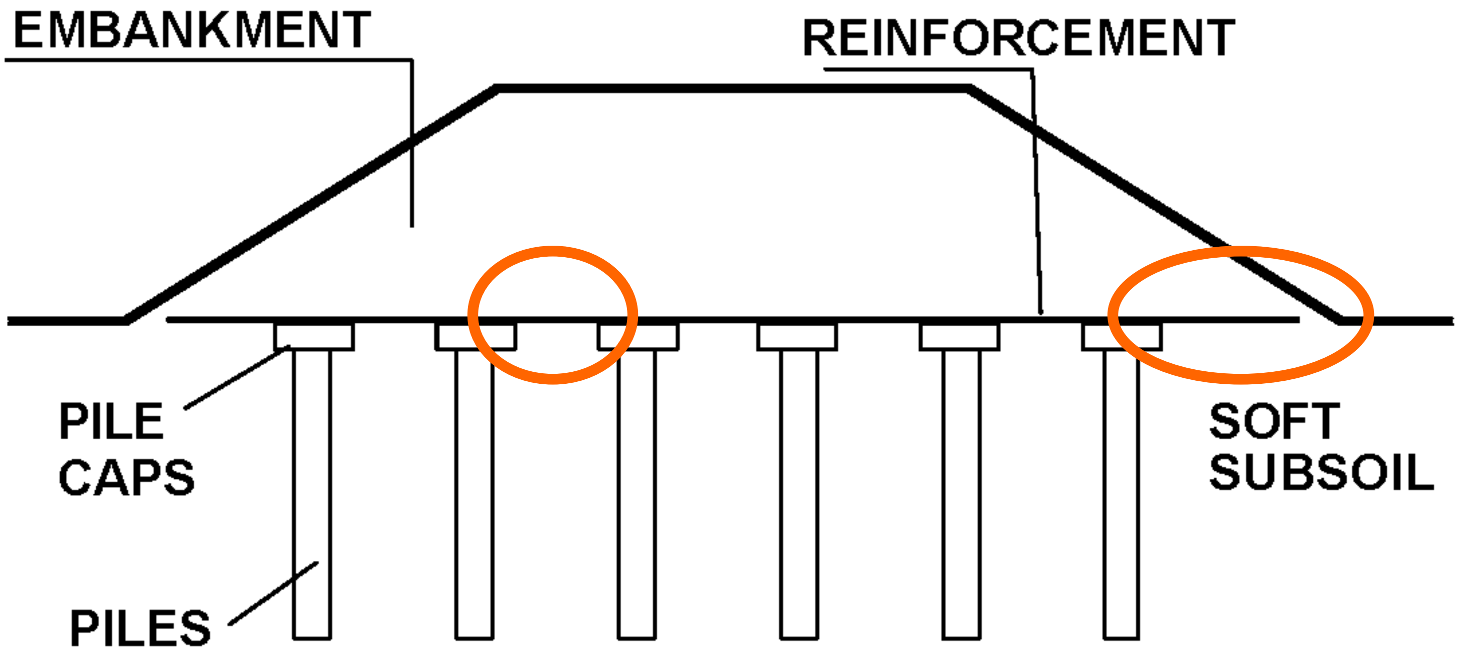
HUESKER Bridge abutment test
LGA Nuremberg, 2006

6. The behavior of the sill bank is like on an even surface, and not on a vertical wall.
7. One could directly use the system in a similar situation without any doubts: it is a kind of „certification“.

Supported embankments

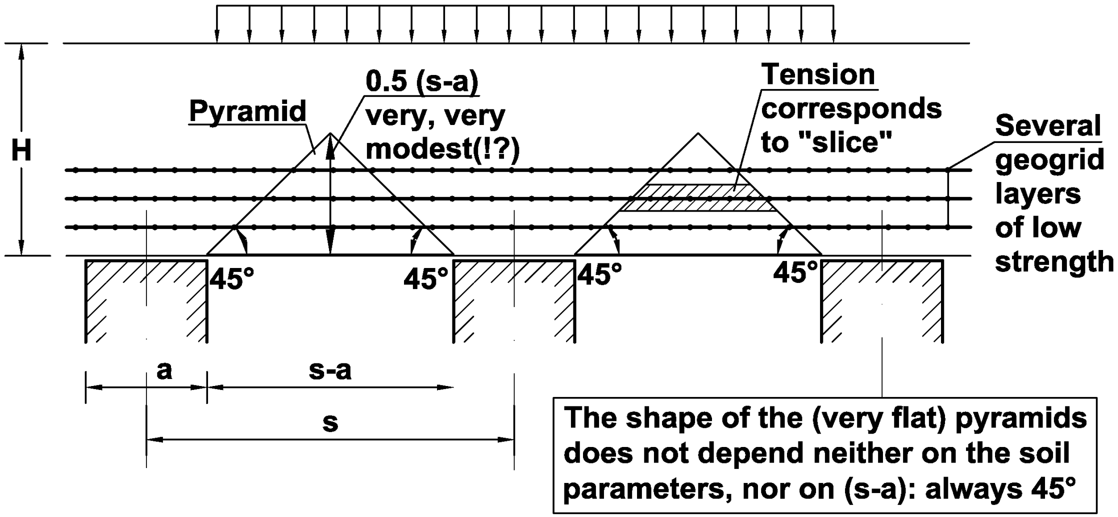
(on (rigid) piles or columns)

Piled embankments: Methods and Some Case Studies



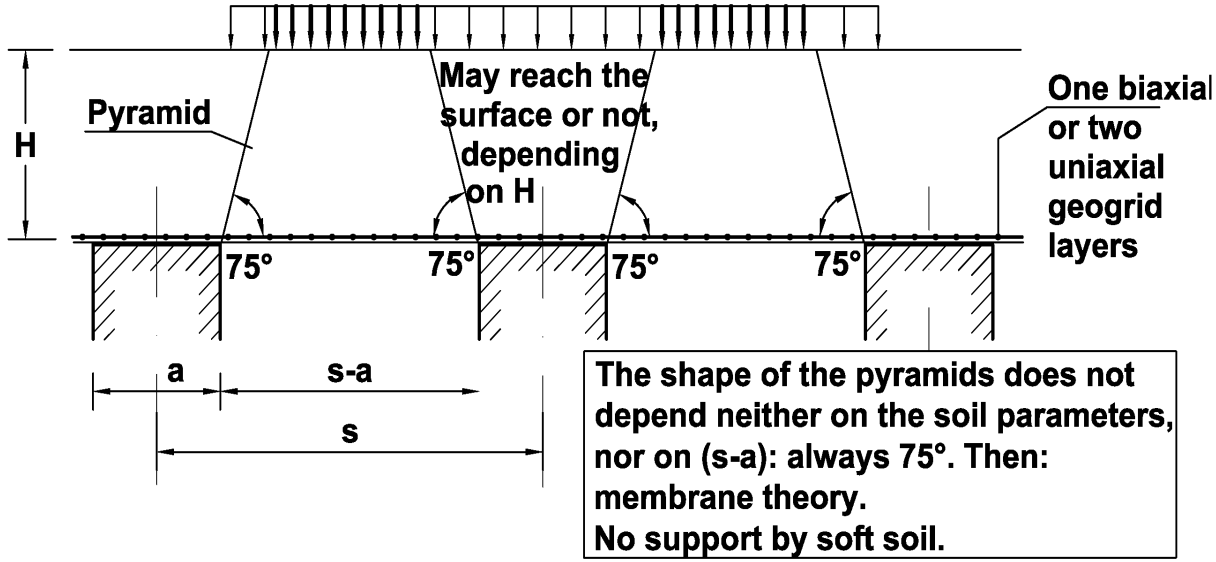
- Vertical bearing elements (piles or columns)
- High-strength uni- or biaxial geosynthetic reinforcement
- One or two layers
- Bridges the soft soil between the piles and takes over the lateral spreading forces

Methods of calculation...



The So Called „Guido Method“

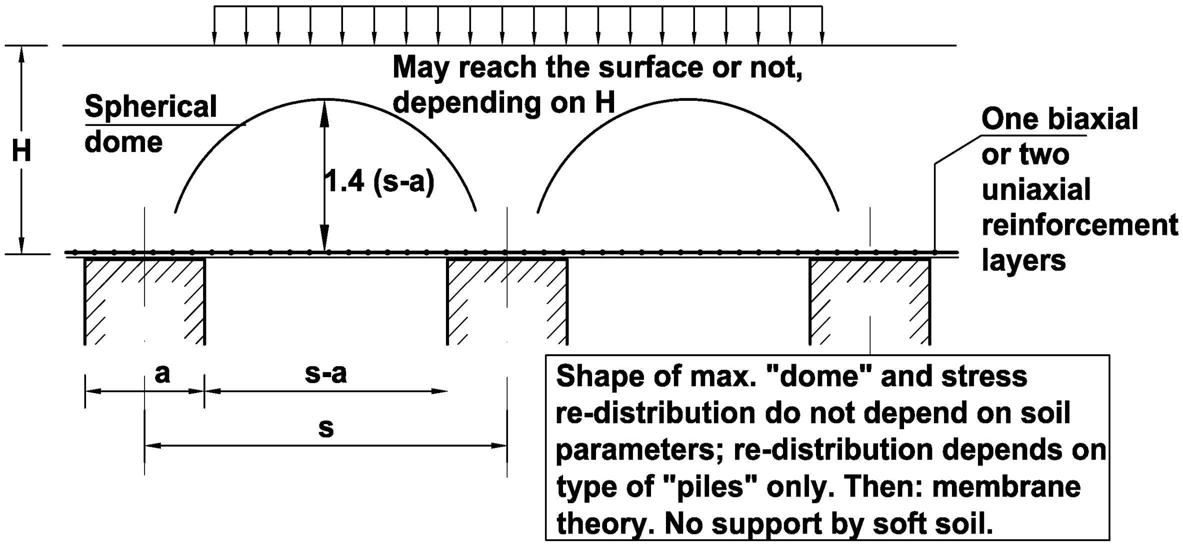
Risky…



The „Swedish Method“

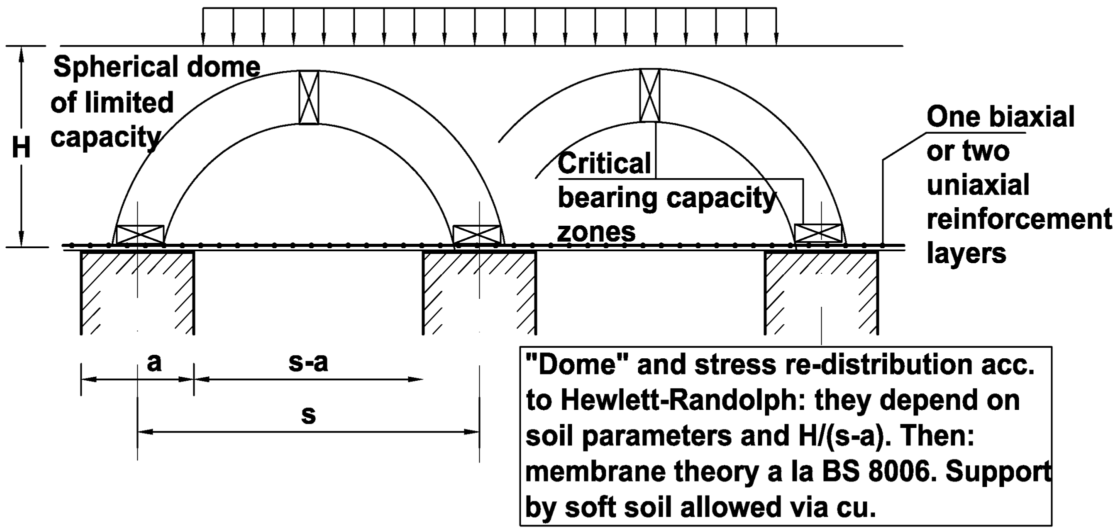
Better…

Methods of calculation...



The „BS 8006 Method"

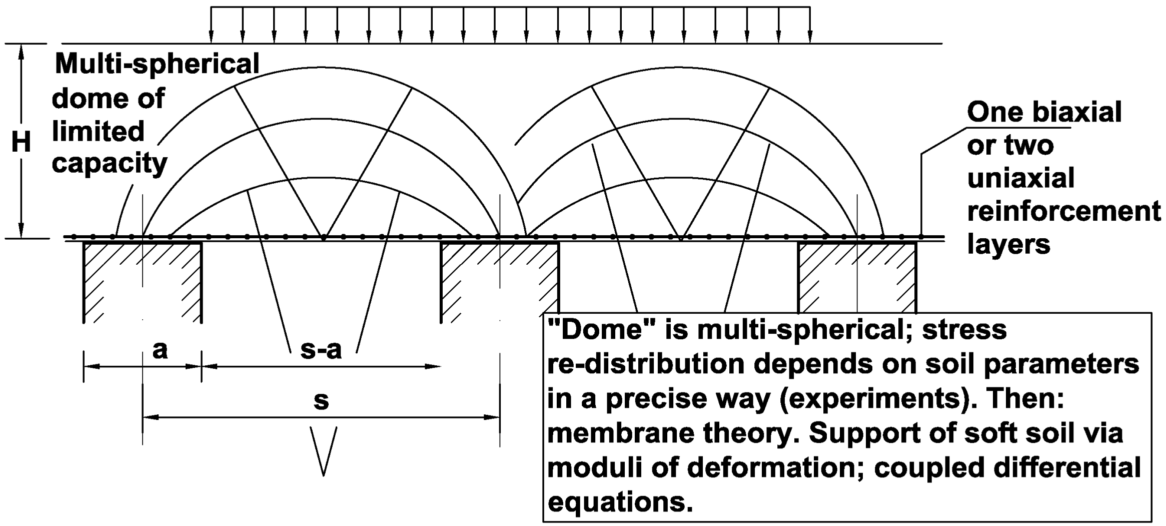
Very popular…



The „Older German Method"

Better than the others...

Methods of calculation...



The „New German Method“ (Final Draft EBGEO)

Supposed to be the best *analytical* today...

HUESKER

Methods of calculation...

Empfehlung 6.9

„Bewehrte Erdkörper auf

punkt- oder linienförmigen Traggliedern“

Bearbeiter:

Prof. Dr.-Ing. habil. Göbel, Dresden

Prof. Dr.-Ing. Kempfert, Kassel

Dr.-Ing. Alexiew, Gescher

Dr.-Ing. Trunk, Germendorf

Dipl.-Ing. Dollowski, Bonn

Dipl.-Ing. Heitz, Kassel

Dipl.-Ing. Hubal, München

Dipl.-Ing. Vogel, München

Dipl.-Ing. Vollmert, Espelkamp

Endfassung (12. Fassung) vom 29.11.2006

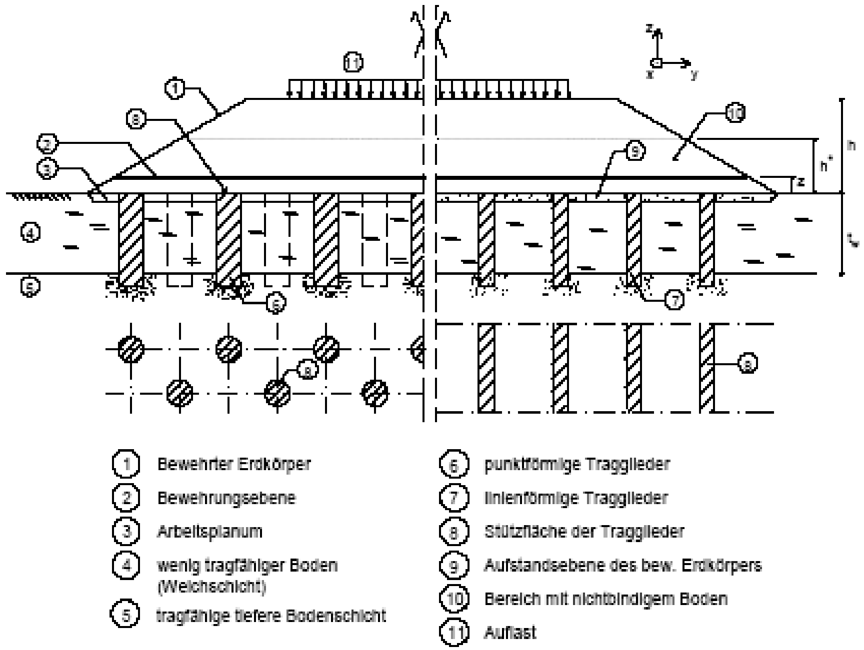
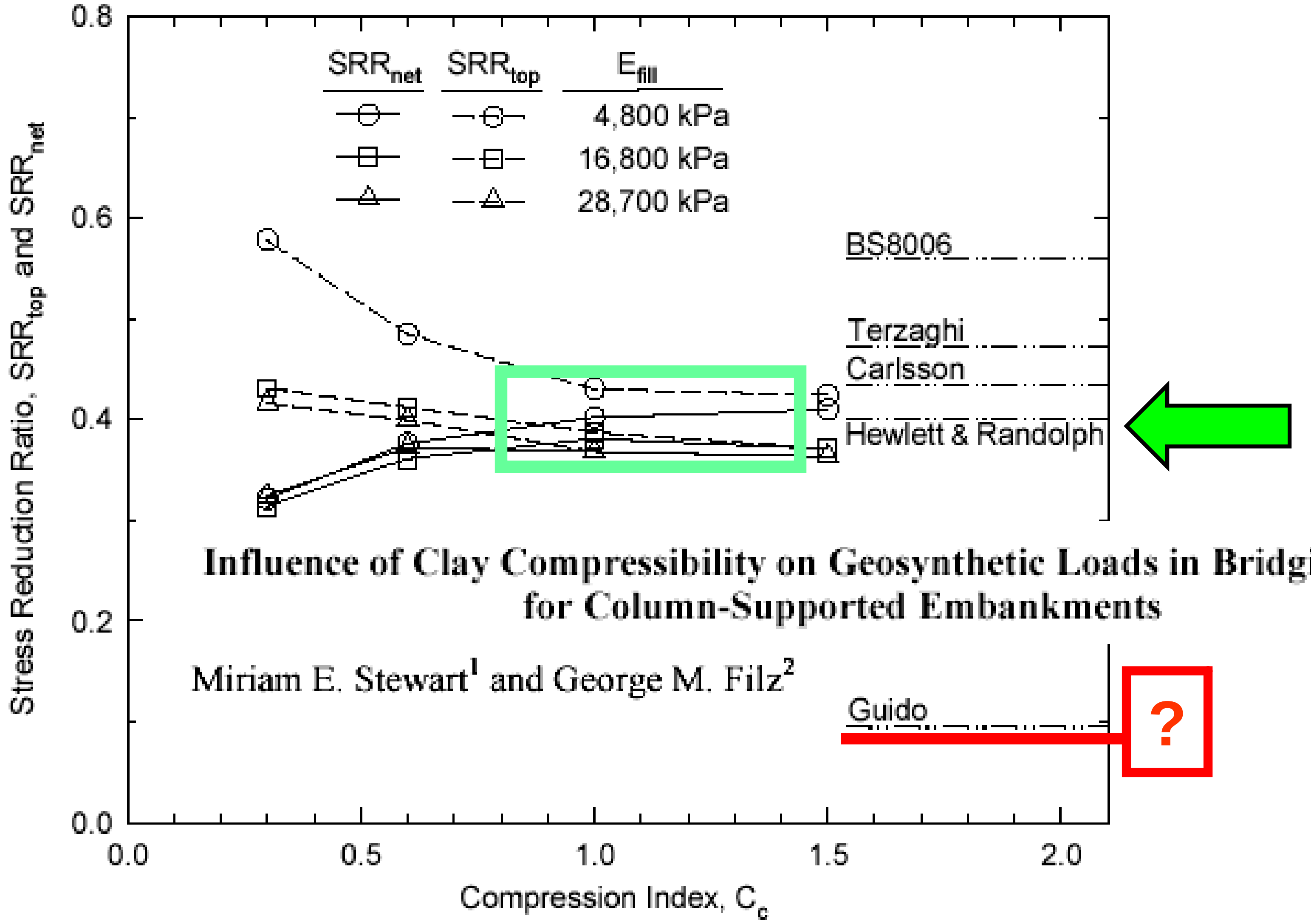


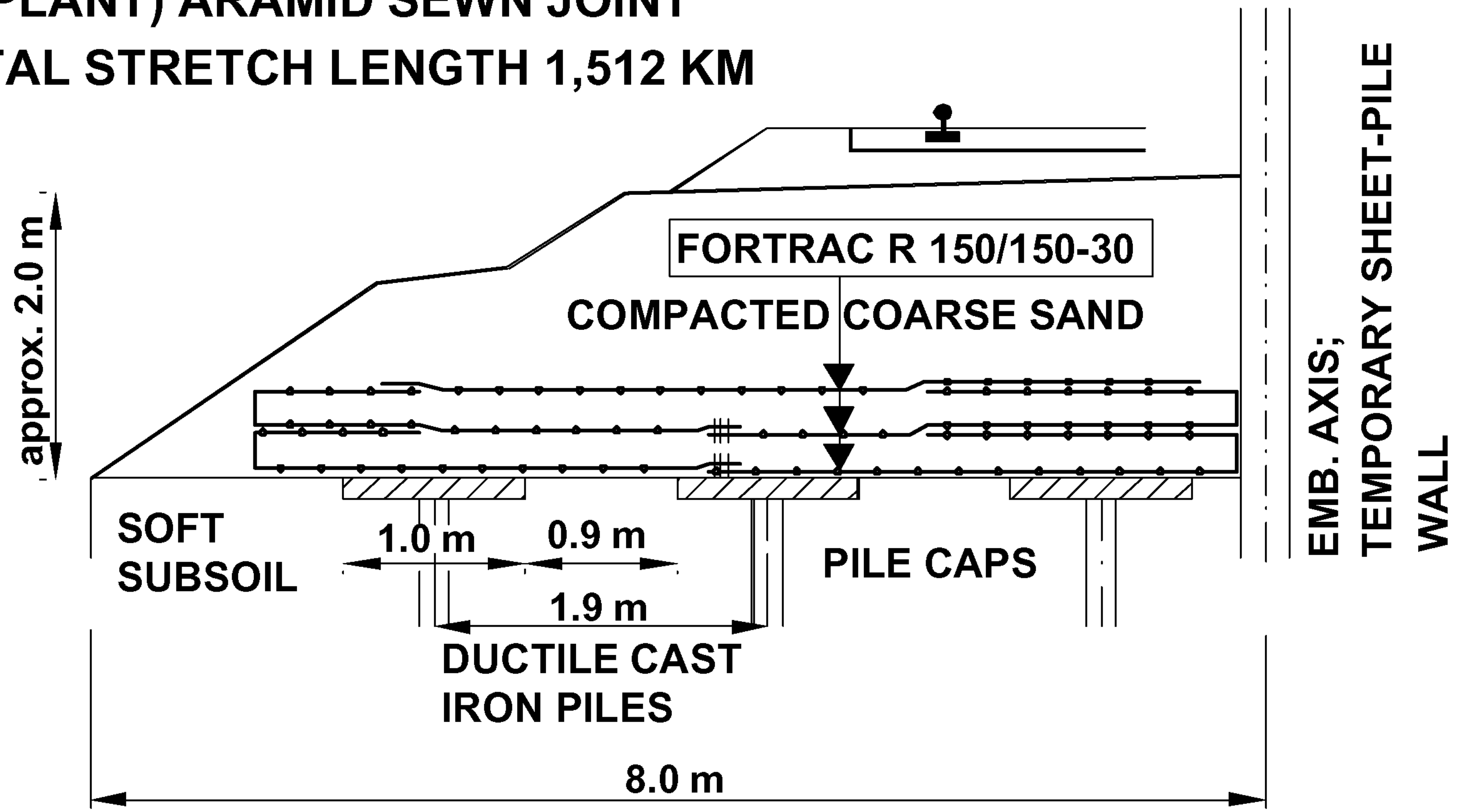
Bild 6.9-1: Bewehrter Erdkörper über punkt- oder linienförmigen Traggliedern am Beispiel einer Dammgründung

Methods of calculation...



German Rail, Werder-Brandenburg, 1993-1994
1st German job on piles in operation
Geogrids FORTRAC 150/150

RAIL LINK RECONSTRUCTION MAGDE
STRETCH WERDER-BRANDENBURG
GEOGRIDS FORTRAC R 150/150-30
5 M WIDE; 3 LAYERS, INCL: SPECIAL PREFABRICATED
(IN PLANT) ARAMID SEWN JOINT
TOTAL STRETCH LENGTH 1,512 KM

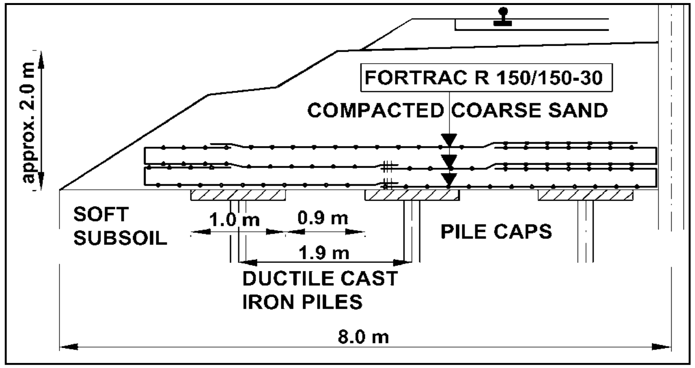


HUESKER

German Rail, Werder-Brandenburg, 1993-1994

1st German job on piles in operation

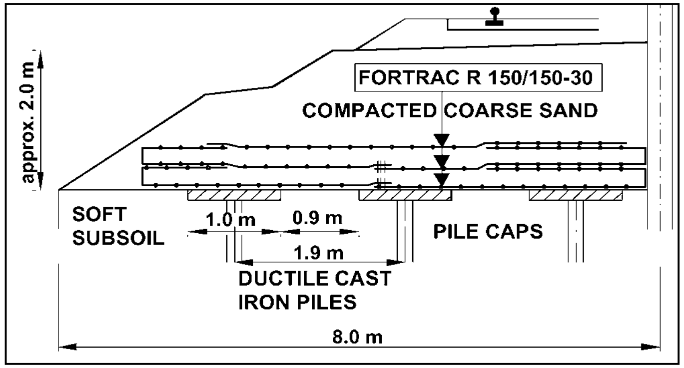
Geogrids FORTRAC 150/150

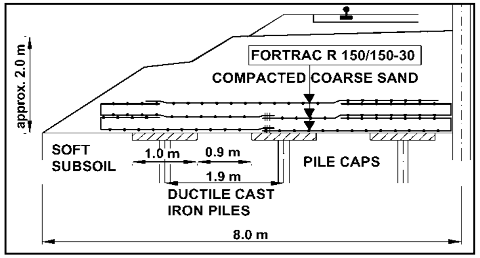


German Rail, Werder-Brandenburg, 1993-1994

1st German job on piles in operation

Geogrids FORTRAC 150/150

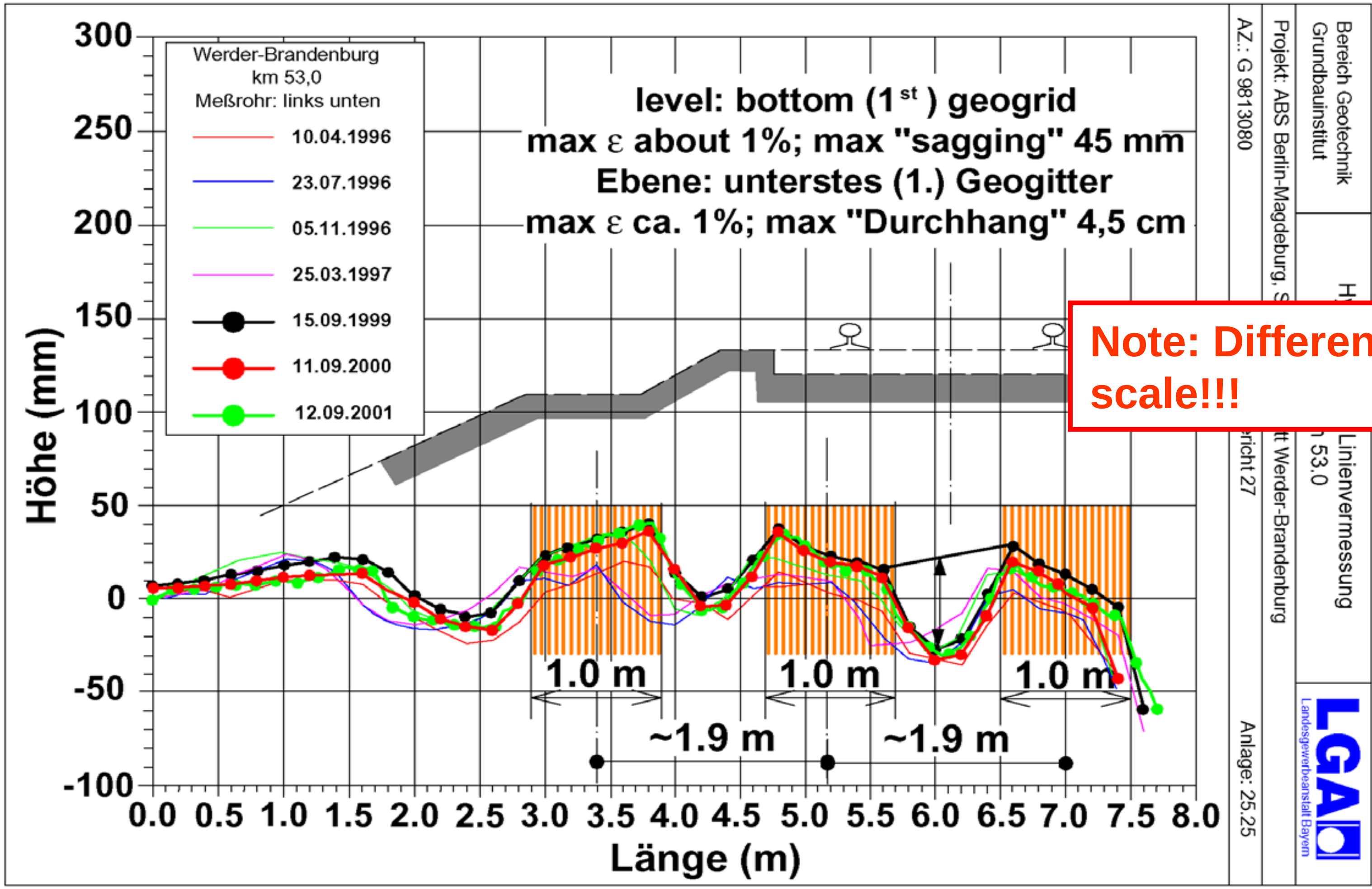




German Rail, Werder-Brandenburg, 1993-1994

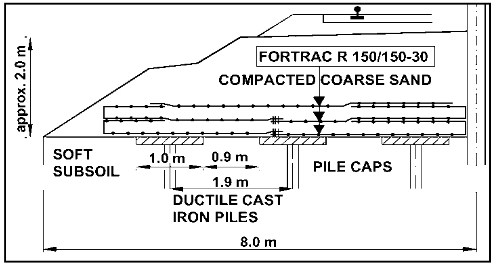
1st German job on piles in operation

Geogrids FORTRAC 150/150



Note: Different vertical scale!!!

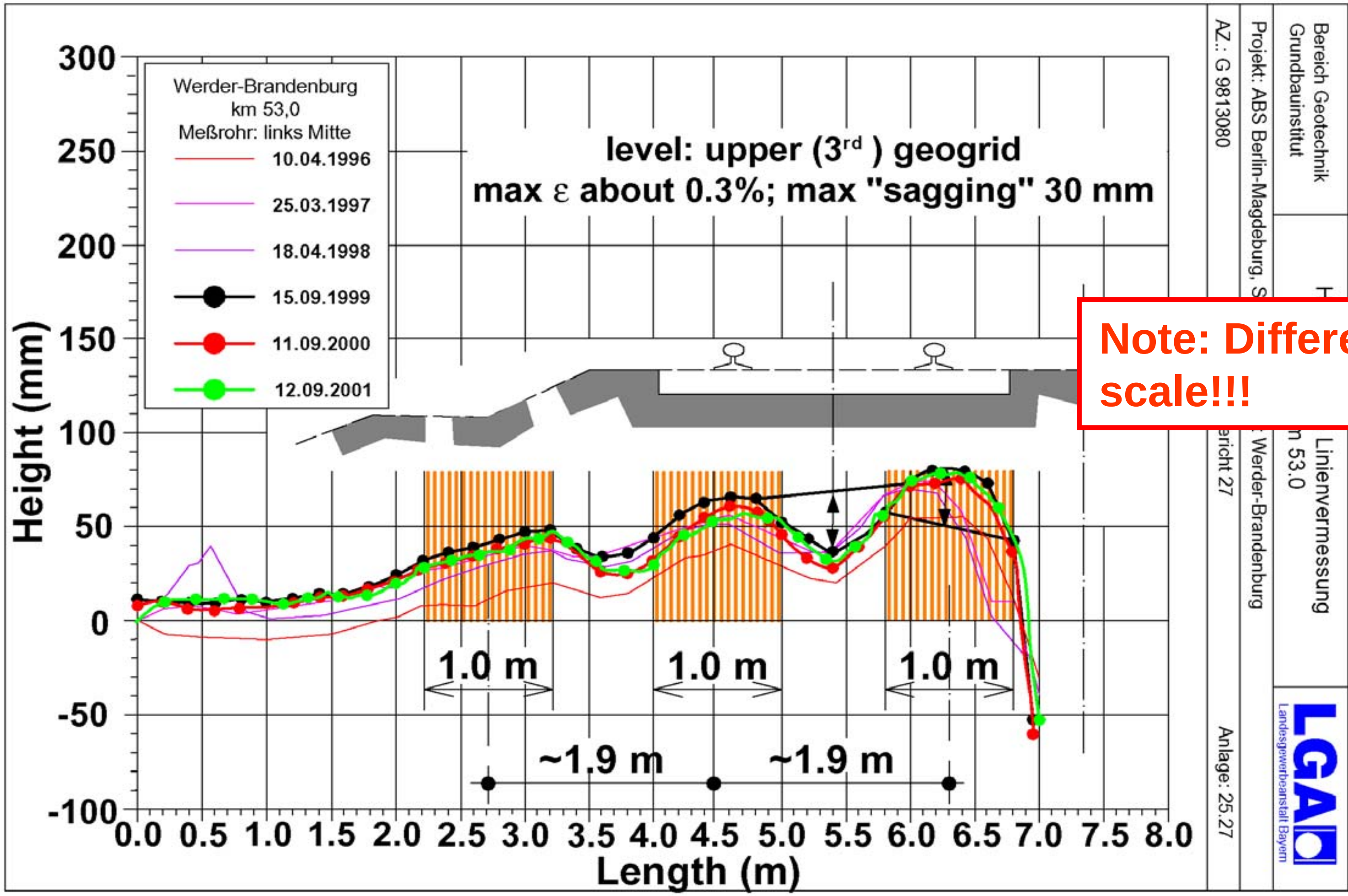
HUESKER



German Rail, Werder-Brandenburg, 1993-1994

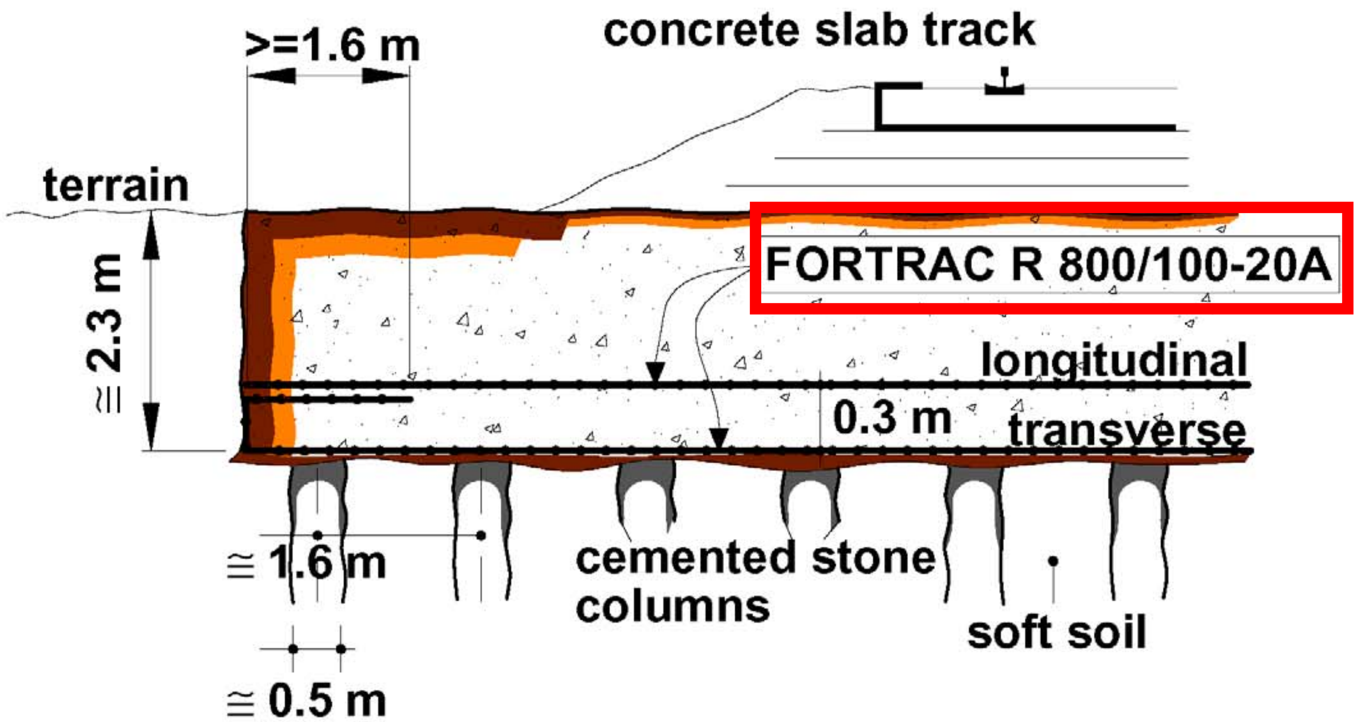
1st German job on piles in operation

Geogrids FORTRAC 150/150



Note: Different vertical scale!!!

ICE high-speed link Hannover - Berlin;1997 Section at Rathenow (Körgraben); 2 layers of uniaxial aramid geogrids

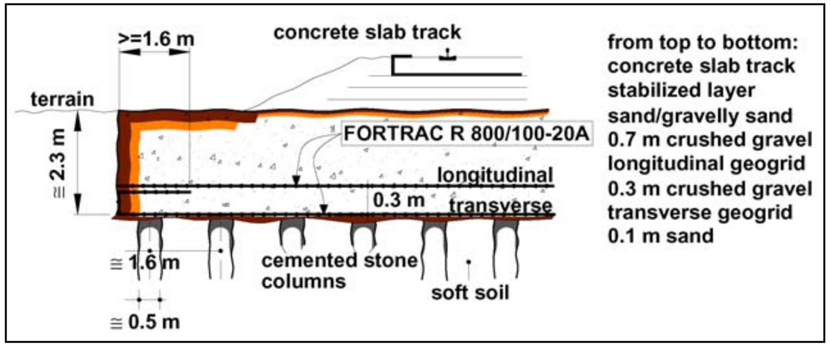


from top to bottom:
concrete slab track
stabilized layer
sand/gravelly sand
0.7 m crushed gravel
longitudinal geogrid
0.3 m crushed gravel
transverse geogrid
0.1 m sand

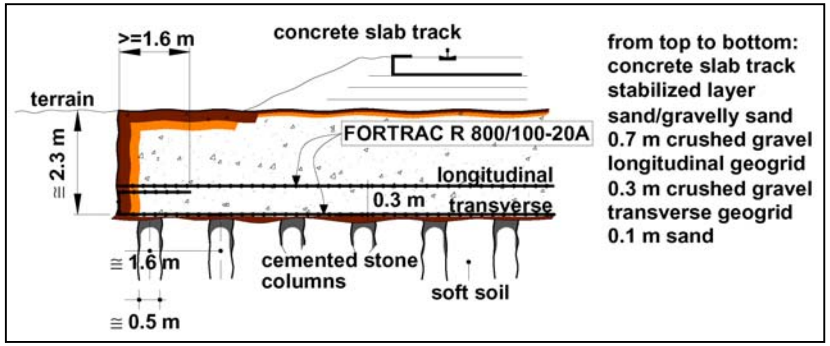
2 layers monoaxial Aramid 800

HUESKER

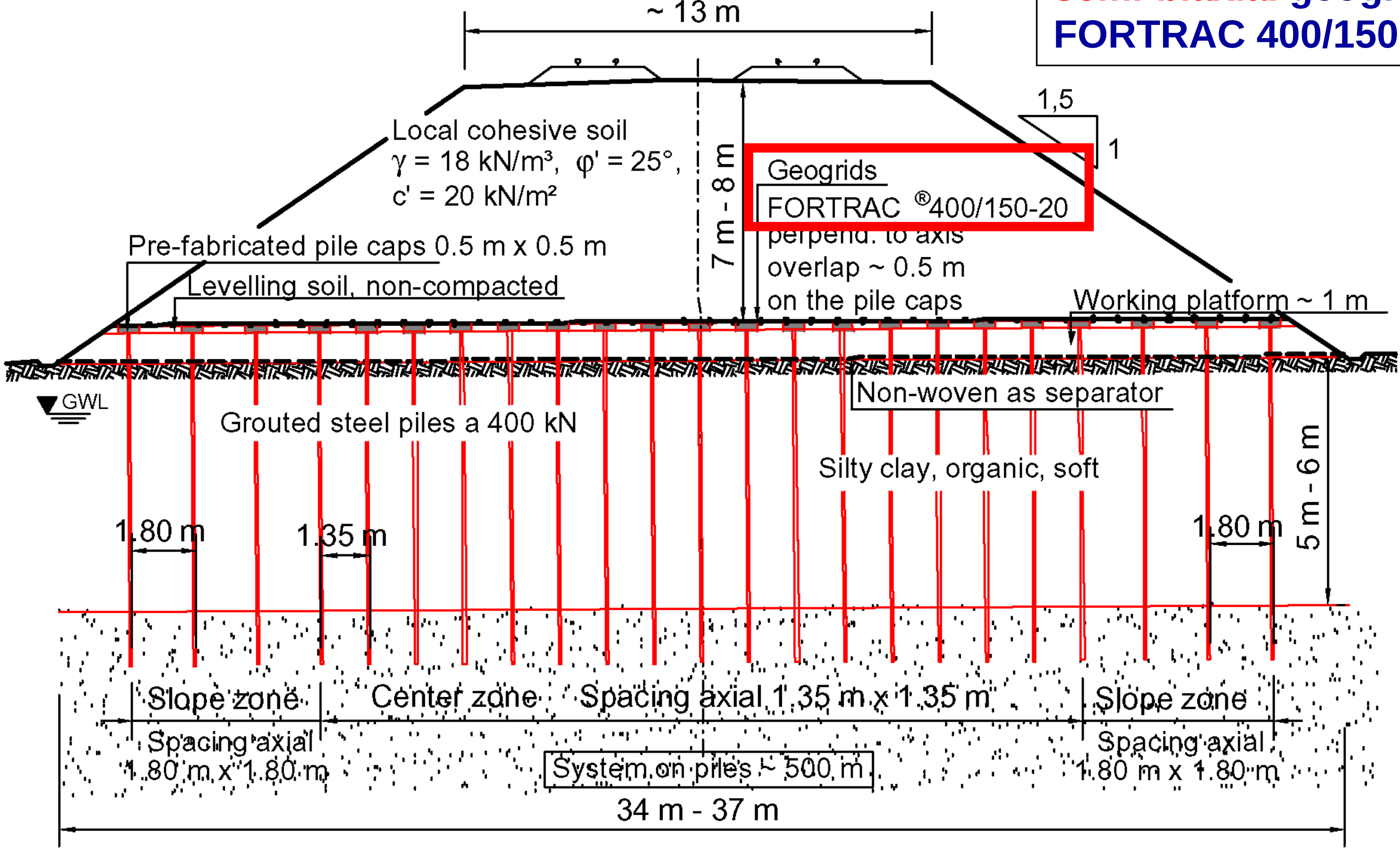
ICE high-speed link Hannover - Berlin;1997 Section at Rathenow (Körgraben); 2 layers of uniaxial aramid geogrids



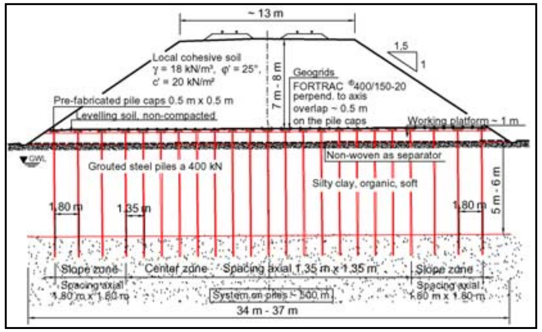
ICE high-speed link Hannover - Berlin;1997 Section at Rathenow (Körgraben); 2 layers of uniaxial aramid geogrids



Ferronorte, River Laje at Chapadao, Brasil, 1998, semi-biaxial geogrids FORTRAC 400/150

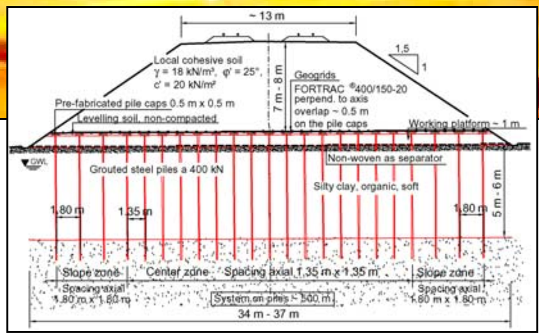


Ferronorte, River Laje at Chapadao, Brasil, 1998, semi-biaxial geogrids FORTRAC 400/150

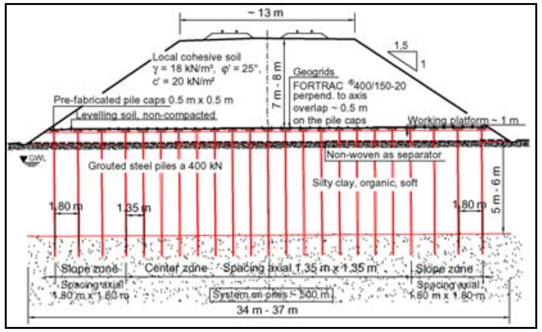


HUESKER

Ferronorte, River Laje at Chapadao, Brasil, 1998, semi-biaxial geogrids FORTRAC 400/150



Ferronorte, River Laje at Chapadao, Brasil, 1998, semi-biaxial geogrids FORTRAC 400/150



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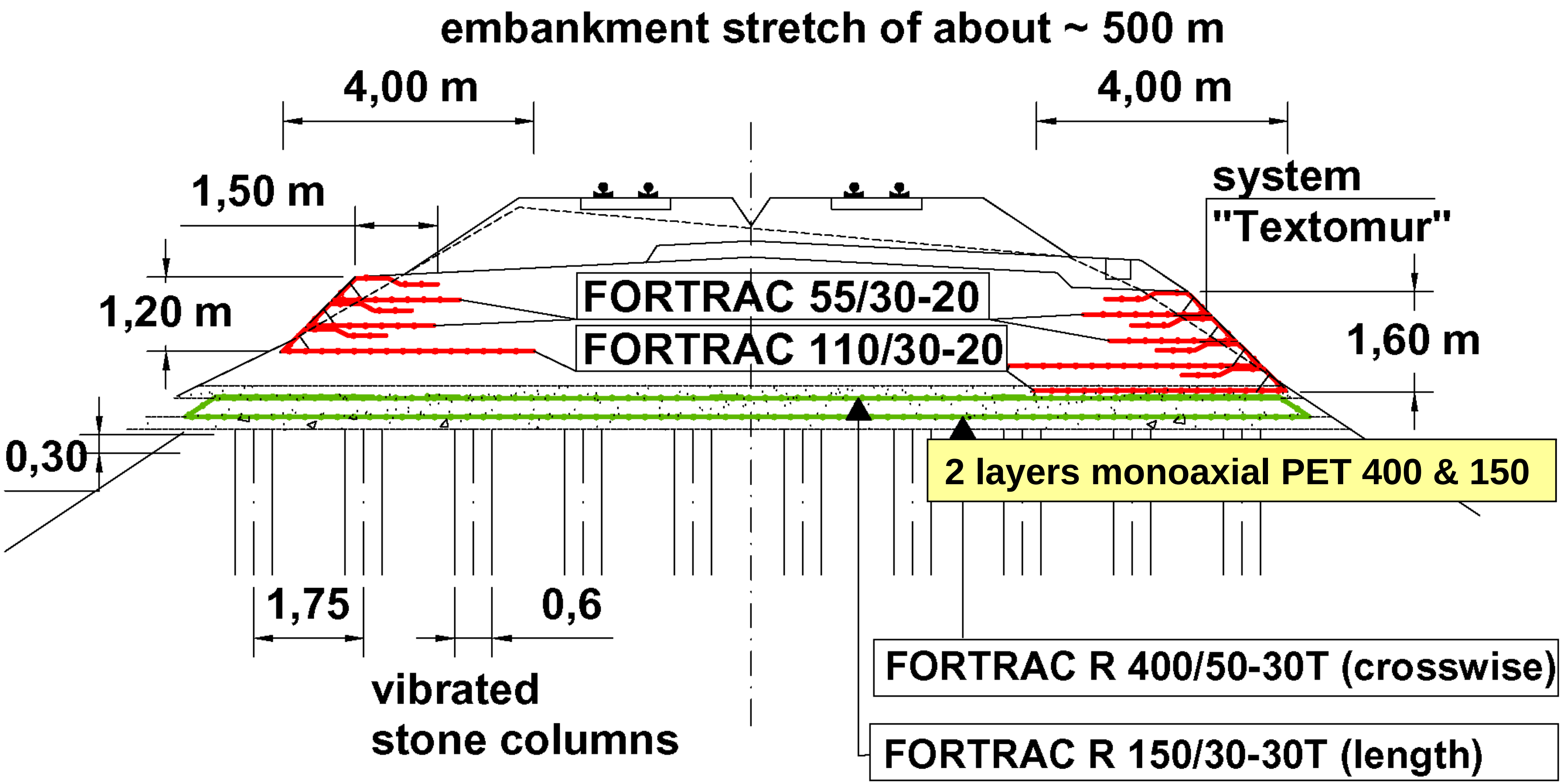
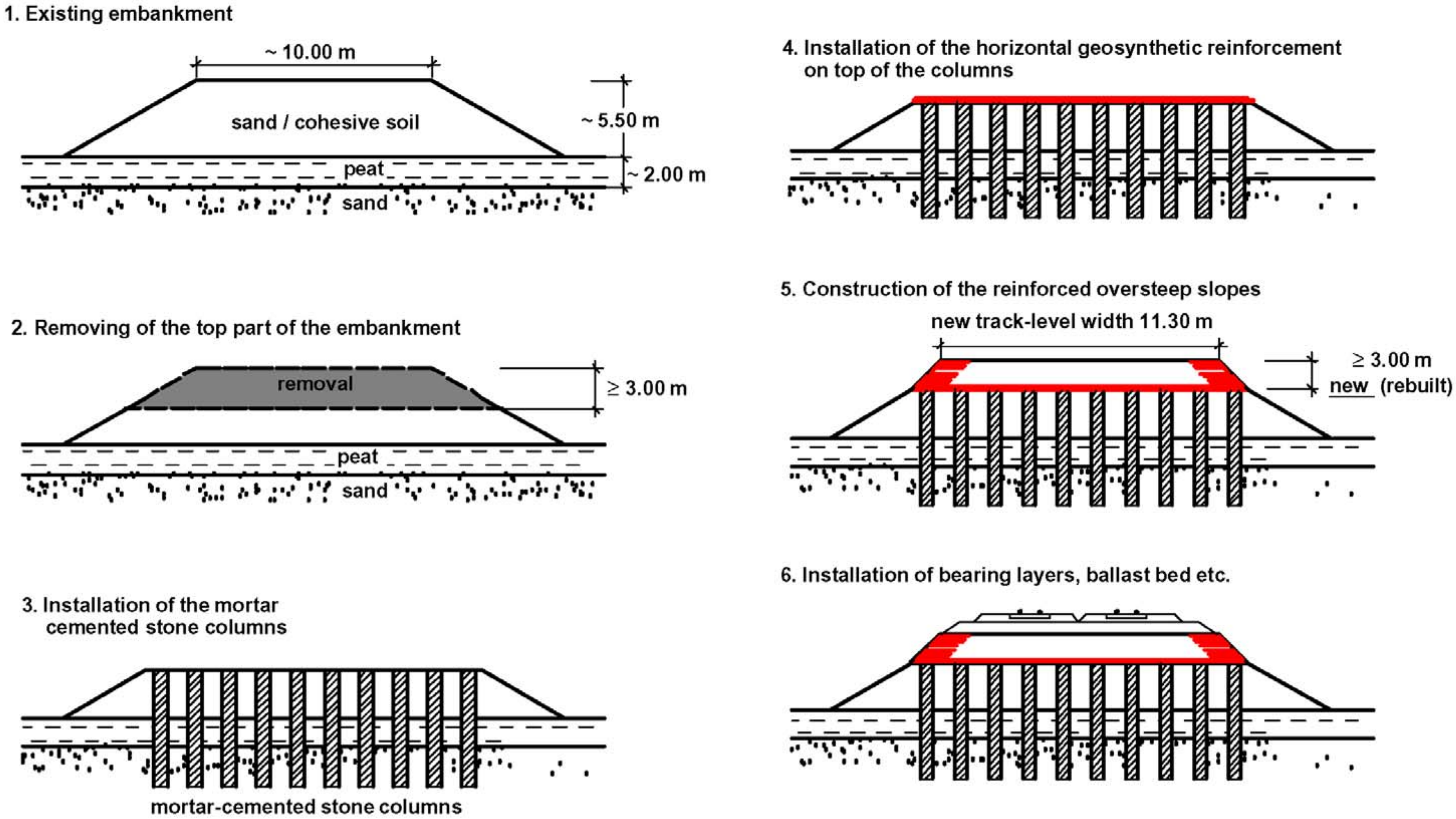
Combined system for German Rail: „piles“ & „slopes“, 1998



"Harper Mühlenbach" ABS Uelzen-Stendal

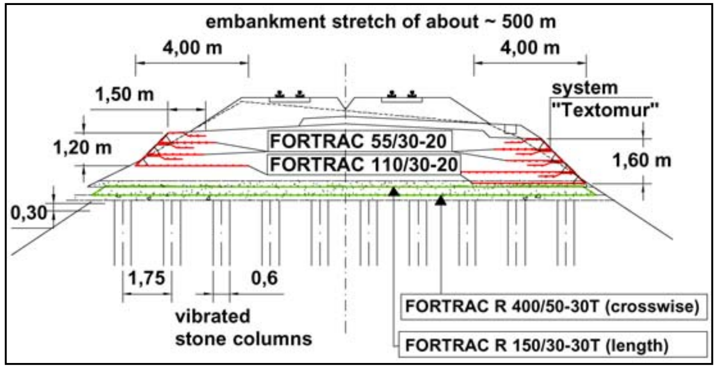
HUESKER

Combined system for German Rail: „piles“ & „slopes“, 1998



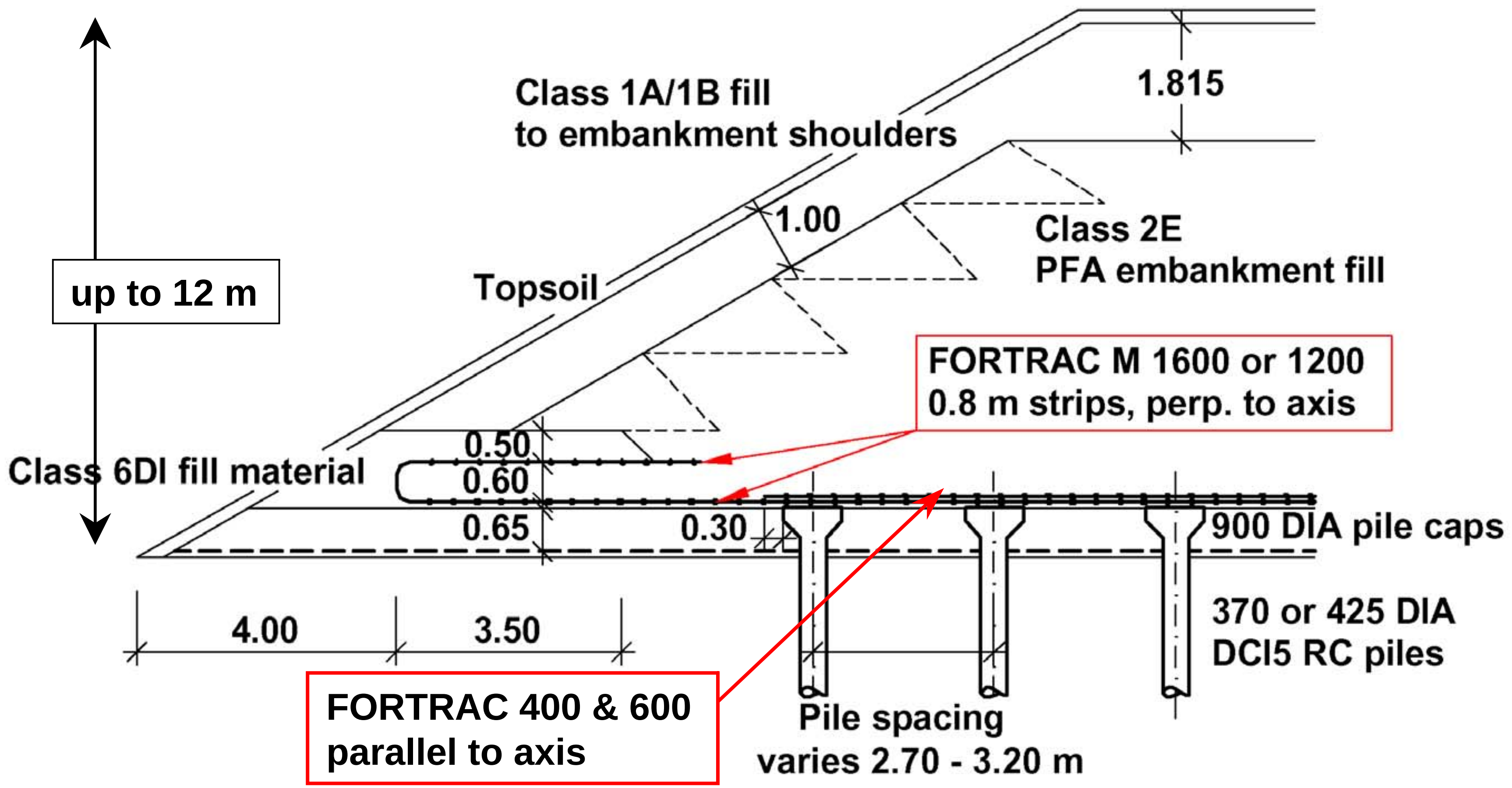
HUESKER

Combined system for German Rail: „piles“ & „slopes“, 1998



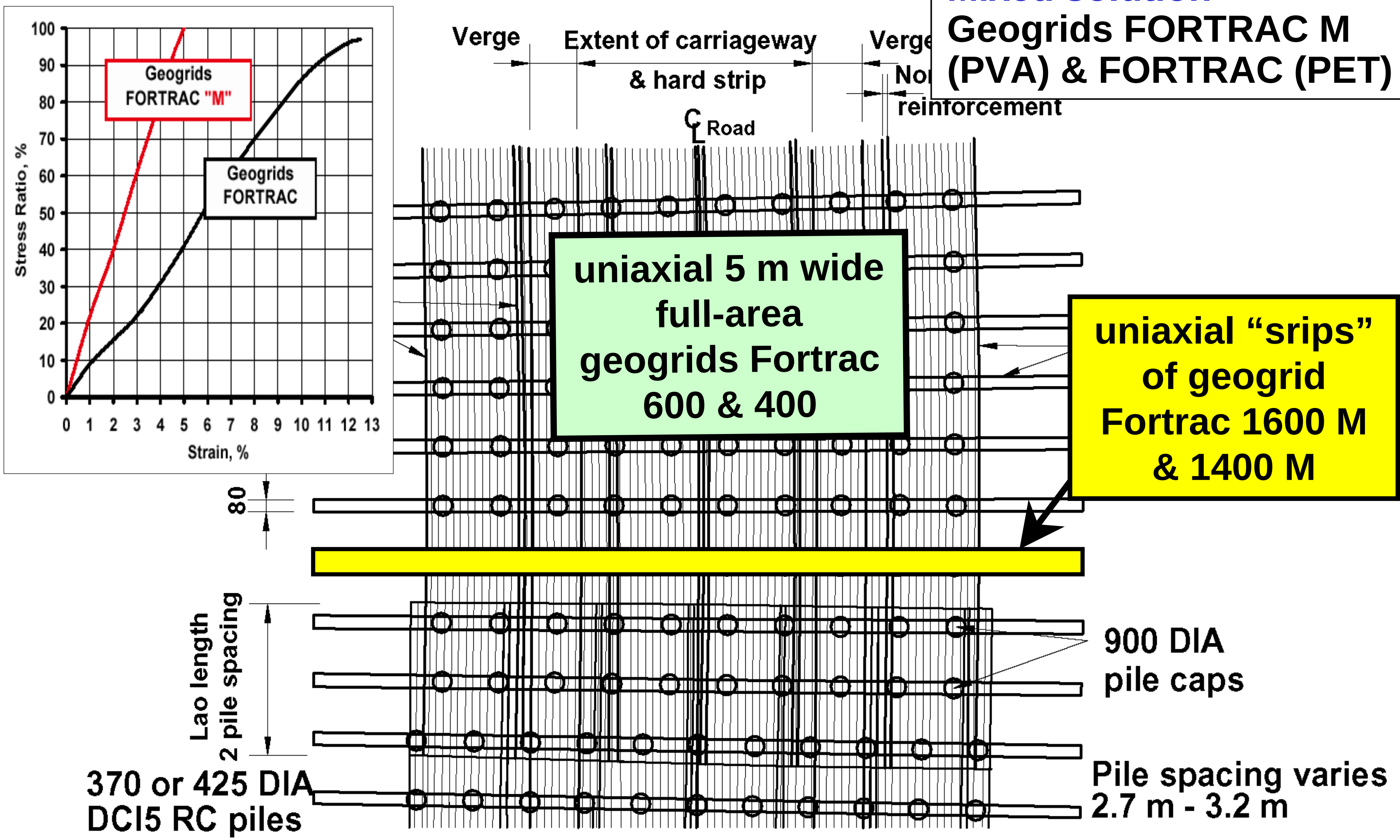
HUESKER

Selby Bypass, UK, 2002
Mixed solution
Geogrids FORTRAC M (PVA) & FORTRAC (PET)



HUESKER

Selby Bypass, UK, 2002
Mixed solution
Geogrids FORTRAC M (PVA) & FORTRAC (PET)



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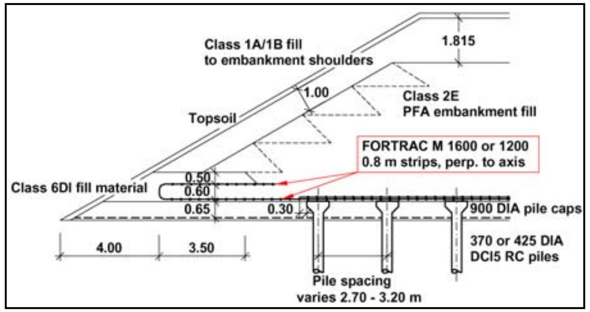
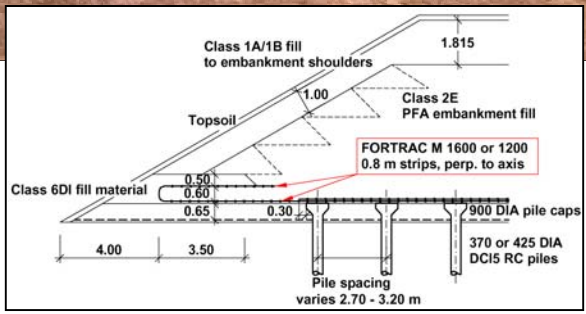


Selby Bypass, UK, 2002
Mixed solution
Geogrids FORTRAC M (PVA) & FORTRAC (PET)

Installation of geogrids



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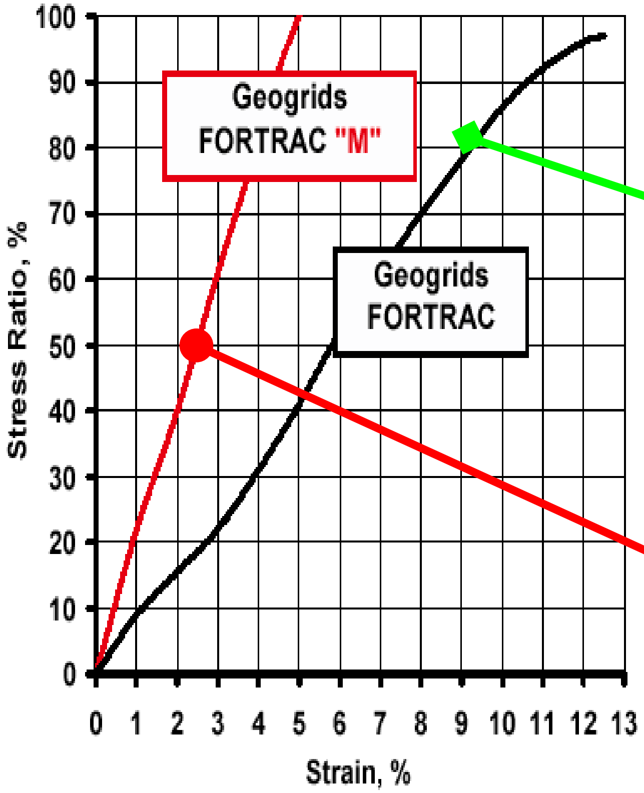
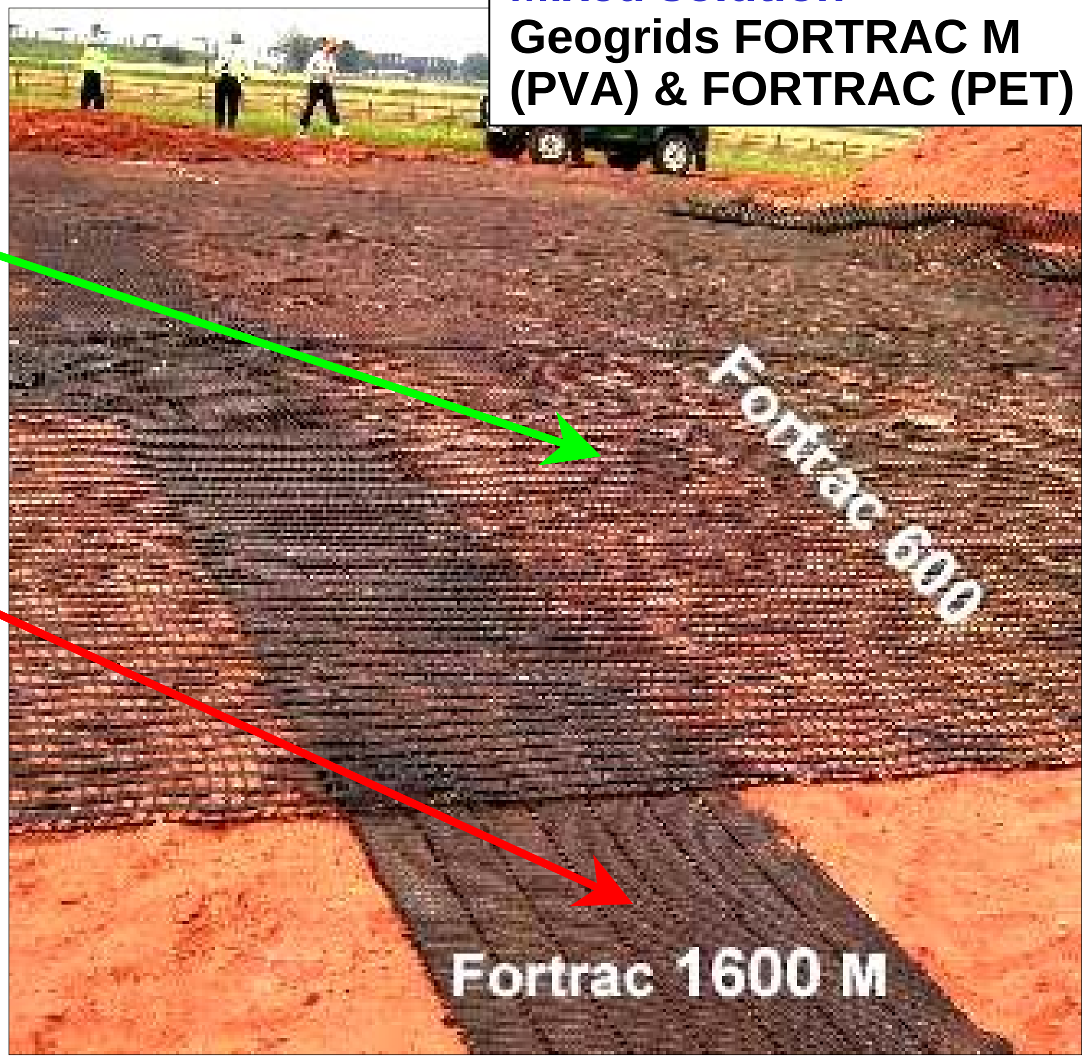
Selby Bypass, UK, 2002
Mixed solution
Geogrids FORTRAC M (PVA) & FORTRAC (PET)

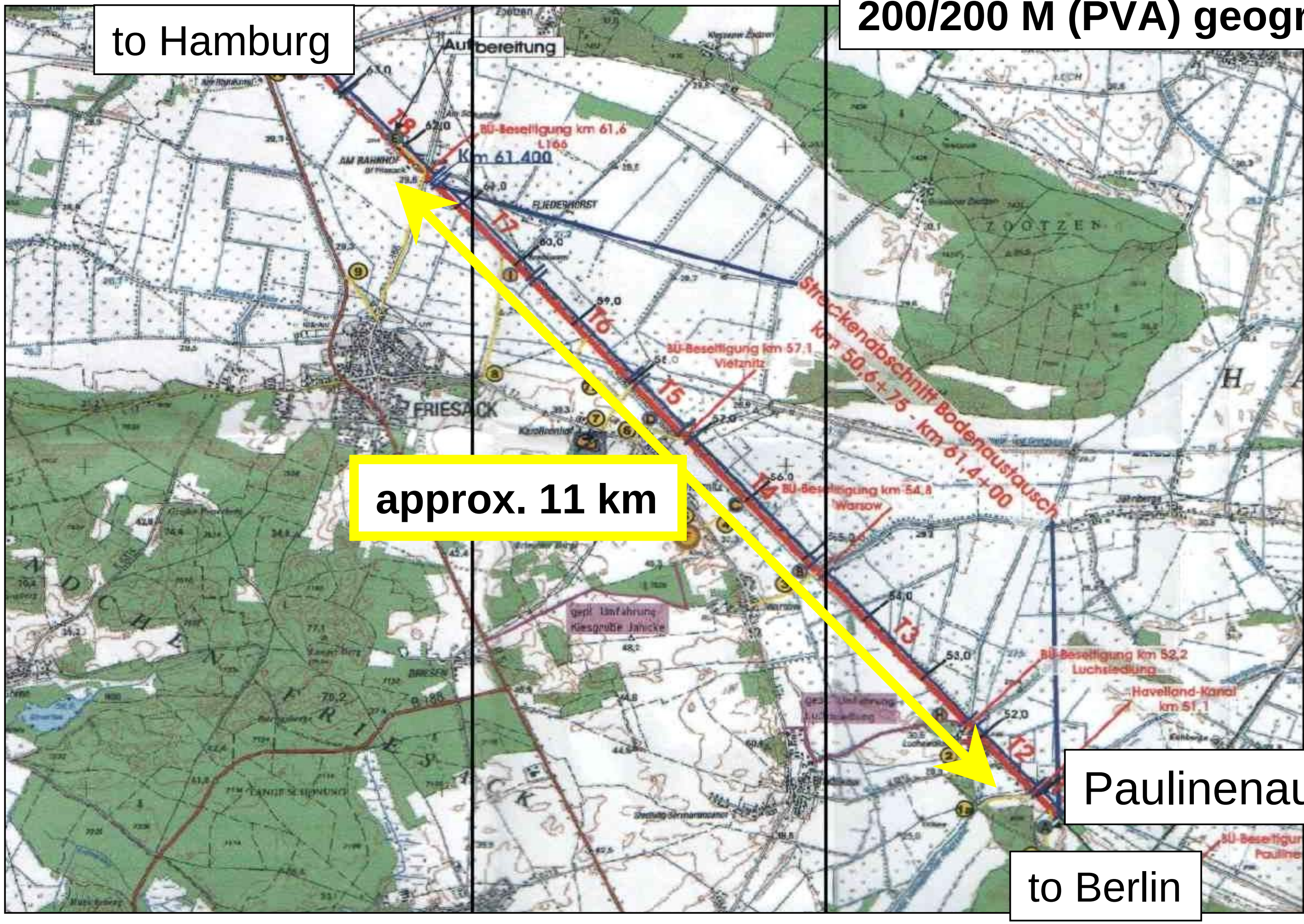




Installation of geogrids

HUESKER

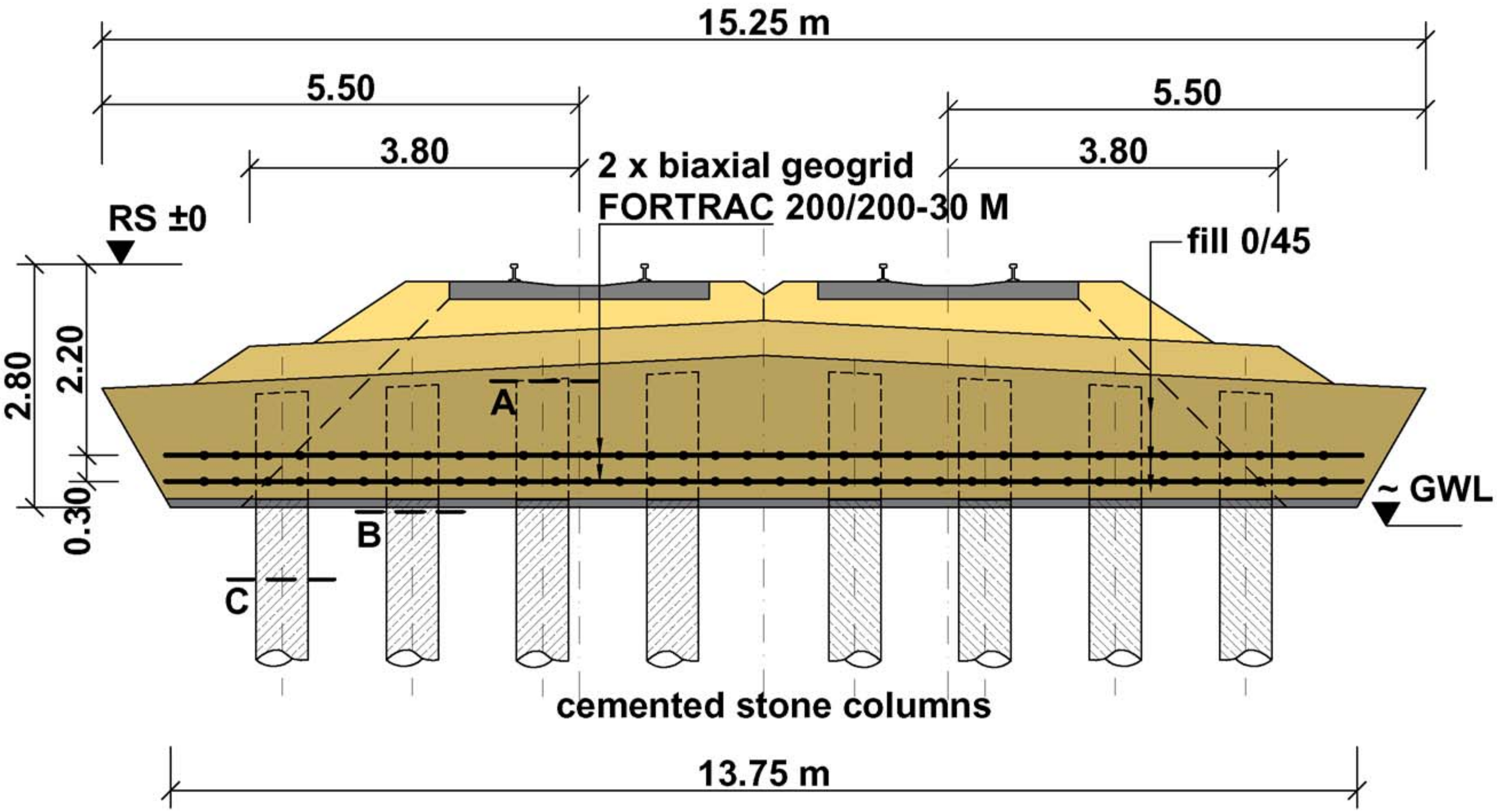
Paulinenenaue, German Rail (DB), 2003, biaxial FORTRAC 200/200 M (PVA) geogrids



HUESKER

Paulinenaue: cross section with two geogrid layers

Paulinenenaue, German Rail (DB), 2003, biaxial FORTRAC 200/200 M (PVA) geogrids

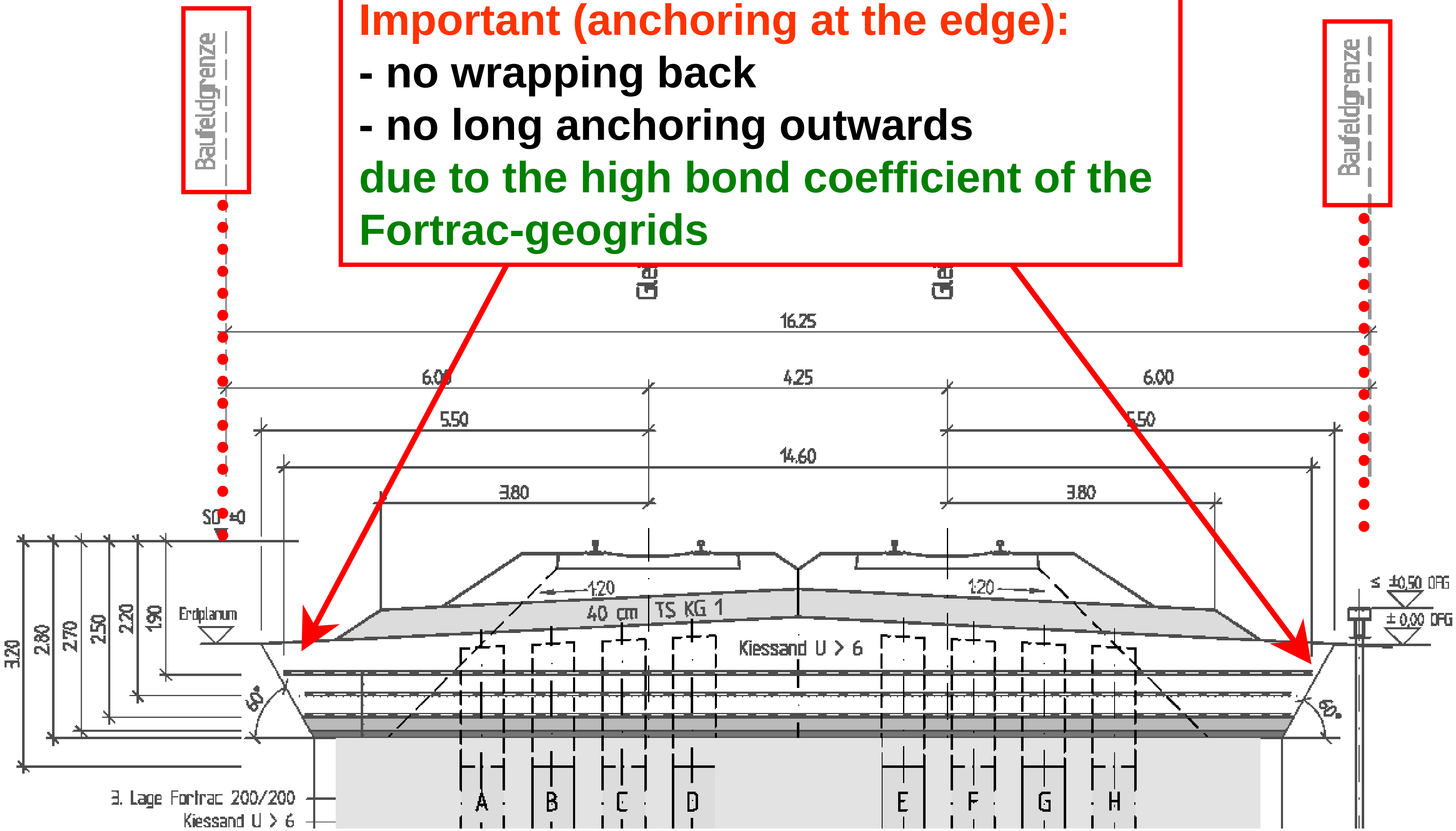


Paulinenenaue, German Rail (DB), 2003, biaxial FORTRAC 200/200 M (PVA) geogrids

Important (anchoring at the edge):

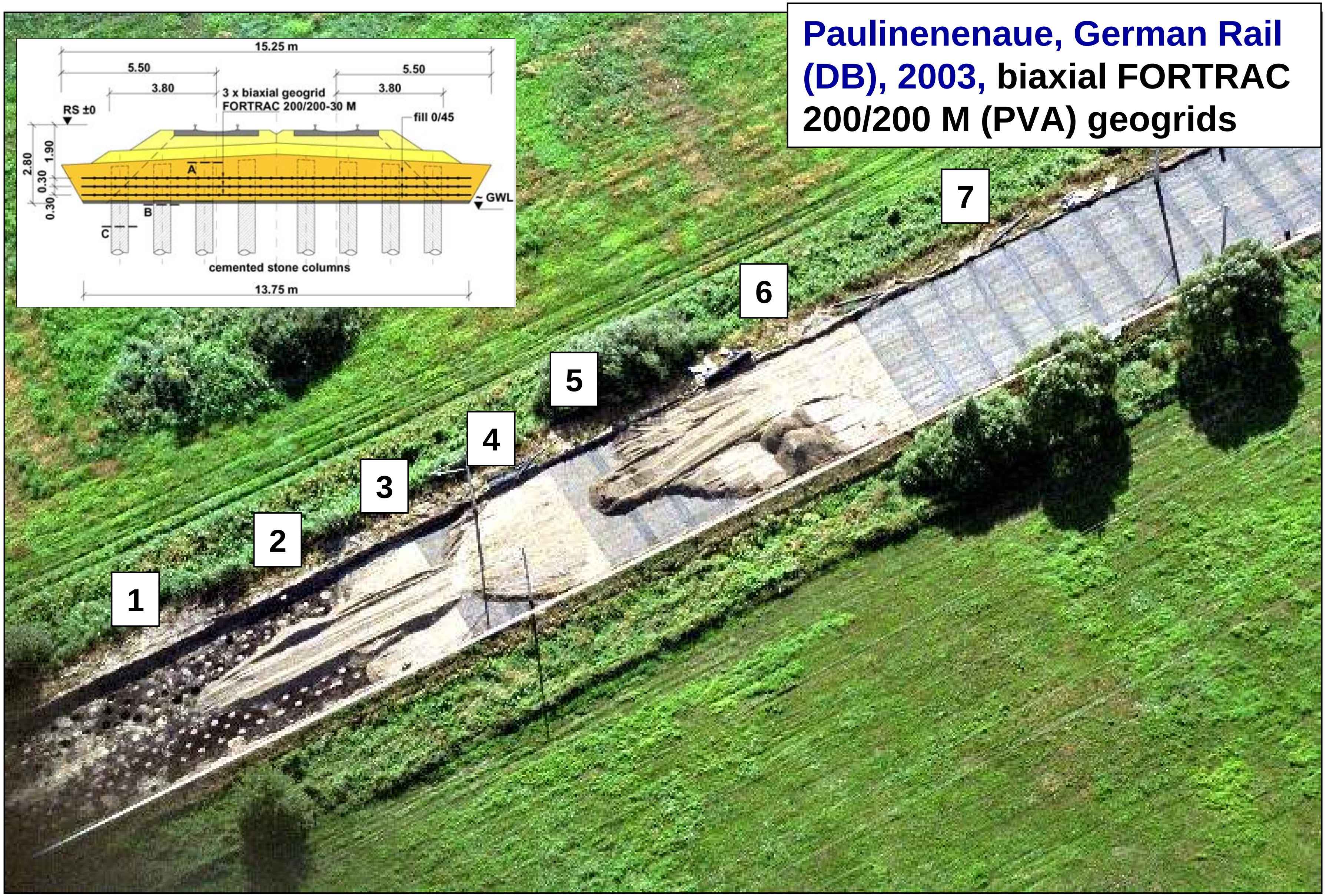
- **no wrapping back**
- **no long anchoring outwards**

due to the high bond coefficient of the Fortrac-geogrids



Paulinenenaue, German Rail (DB), 2003, biaxial FORTRAC 200/200 M (PVA) geogrids

Paulinenenaue, German Rail (DB), 2003, biaxial FORTRAC 200/200 M (PVA) geogrids



Paulinenenaue, German Rail (DB), 2003, biaxial FORTRAC 200/200 M (PVA) geogrids

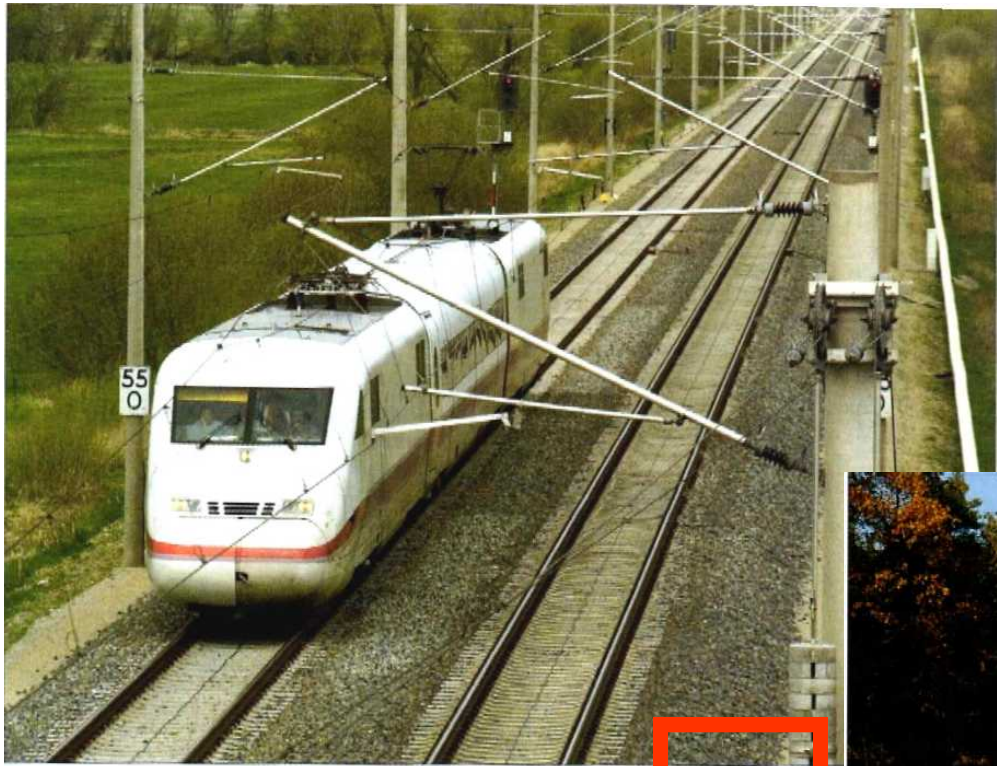
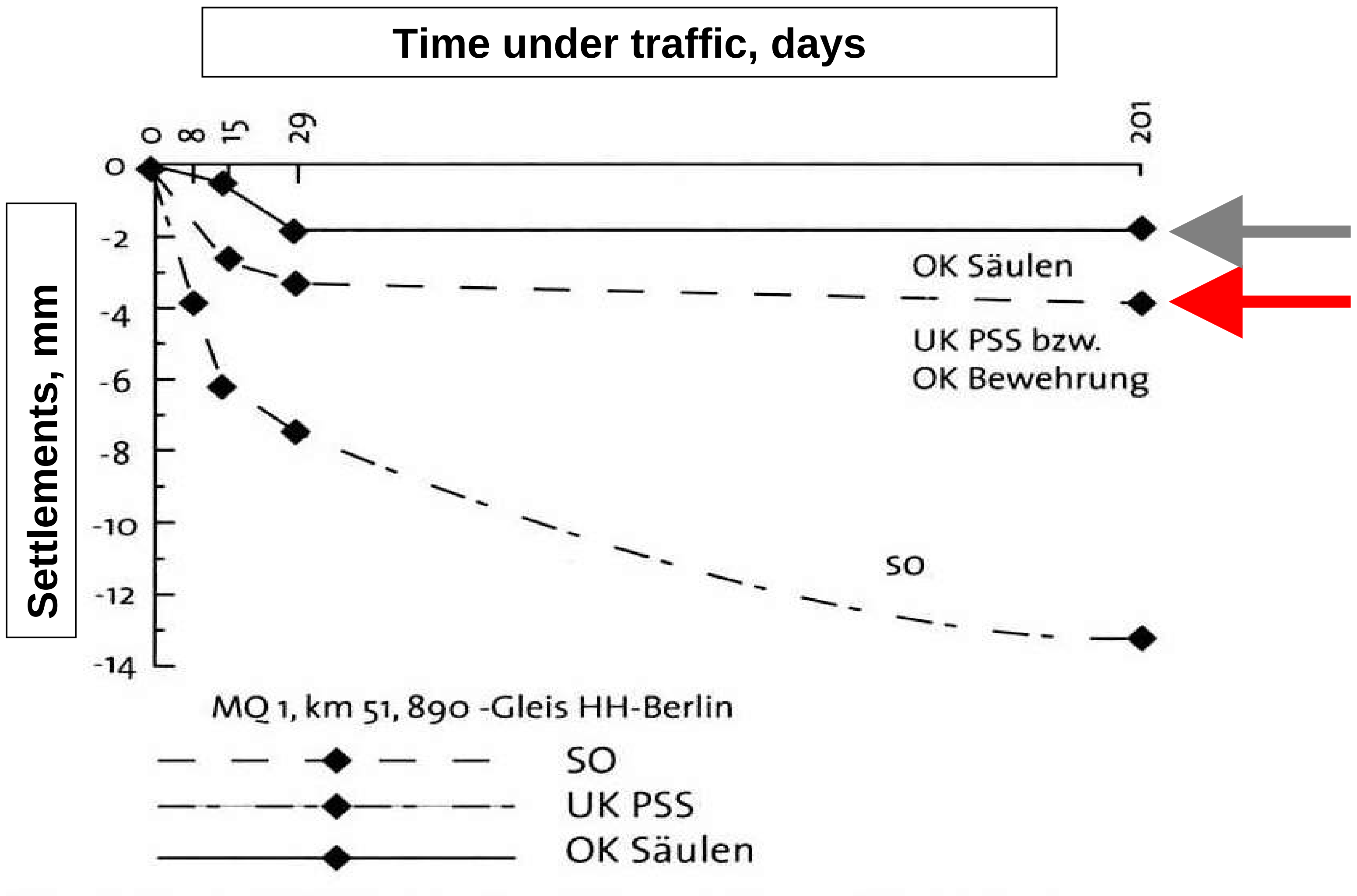


Bild 7: Der Messzug ICE-S auf Abnahmefahrt ABS Hamburg–Berlin mit 253 km/h (Foto

Bild 1: Die Streckengleise Hamburg–Berlin nach dem Umbau (Quelle: DB AG/Bedeschinski)

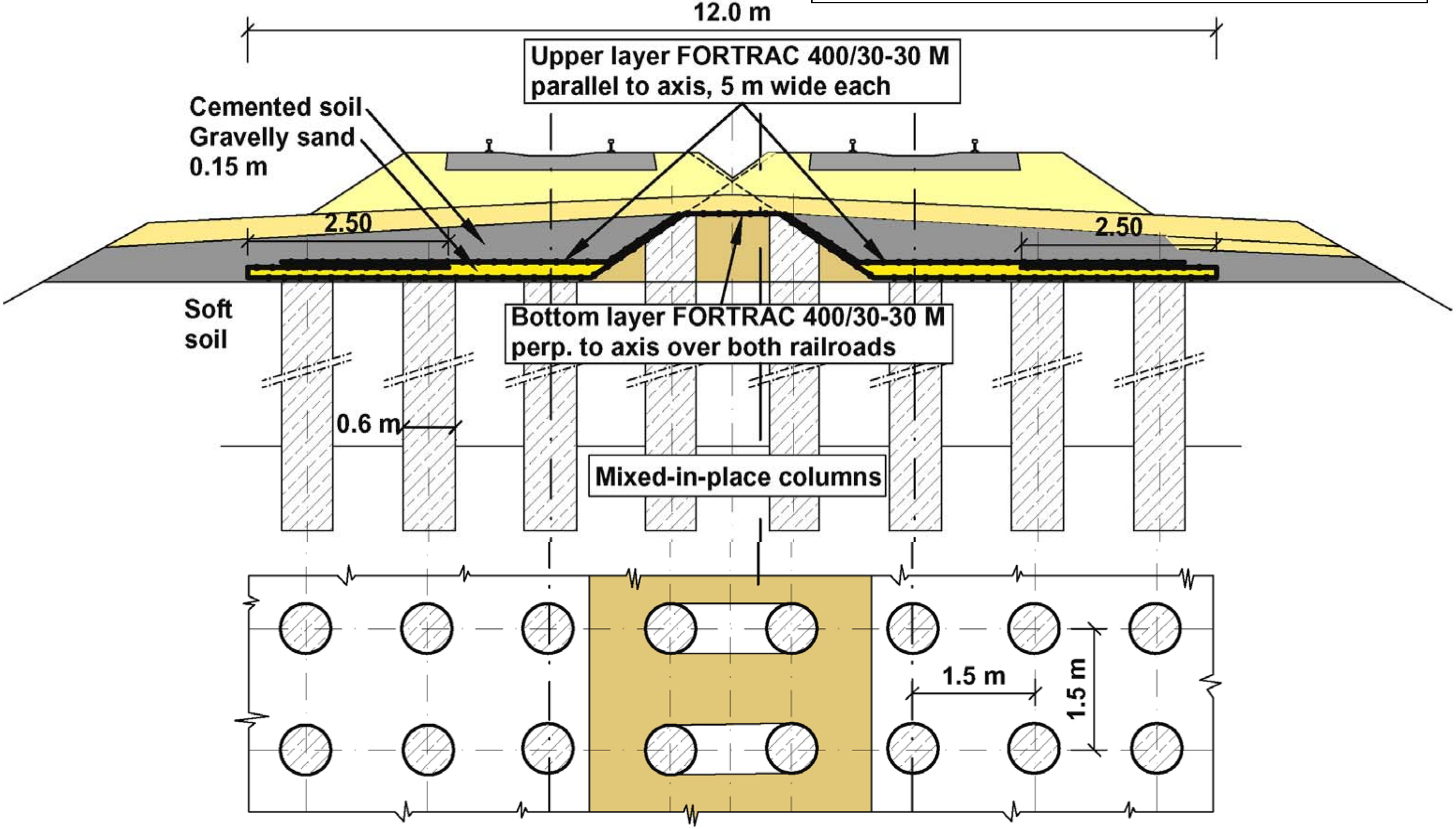
Paulinenenaue, German Rail (DB), 2003, biaxial FORTRAC 200/200 M (PVA) geogrids



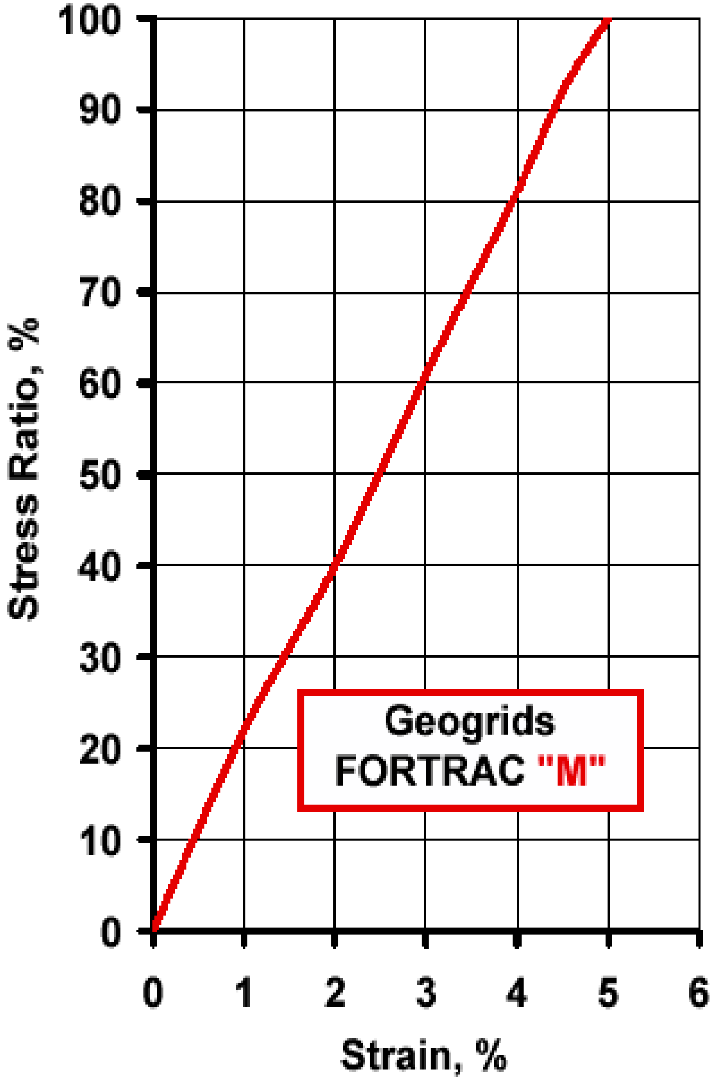
HUESKER

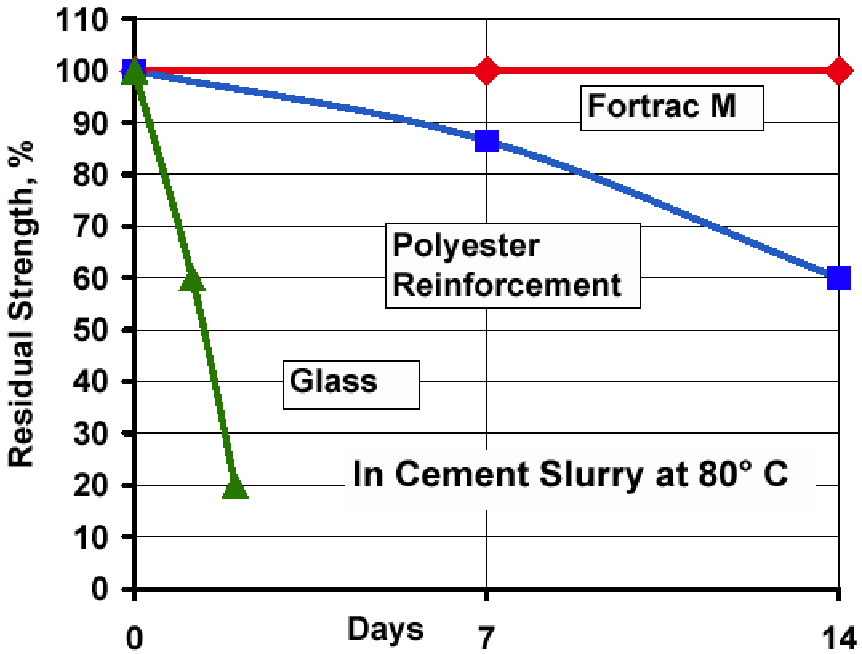
Typical cross section

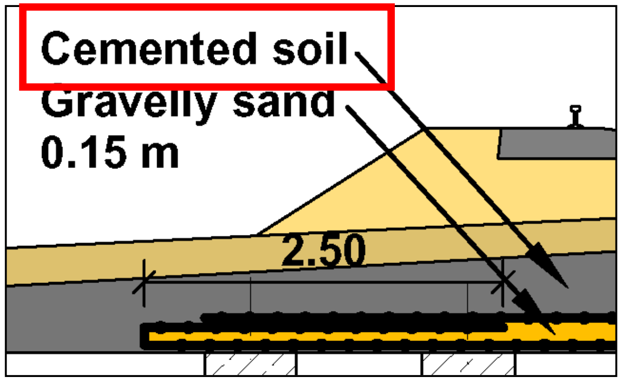
Büchen, German Rail (DB), 2003
geogrids FORTRAC M 400 (PVA)



Büchen, German Rail (DB), 2003
geogrids FORTRAC M 400 (PVA)







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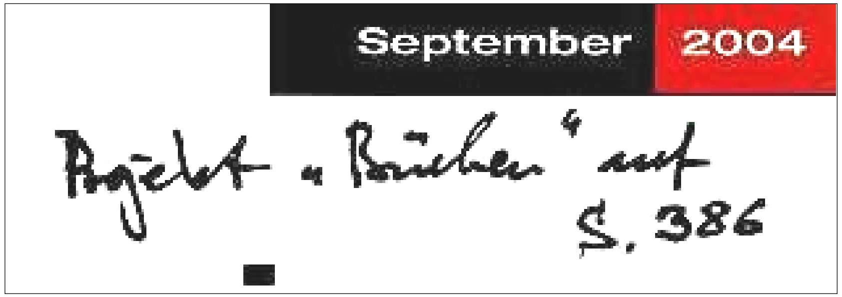
Büchen, German Rail (DB), 2003
geogrids FORTRAC M 400 (PVA)

Büchen, German Rail (DB), 2003
geogrids FORTRAC M 400 (PVA)

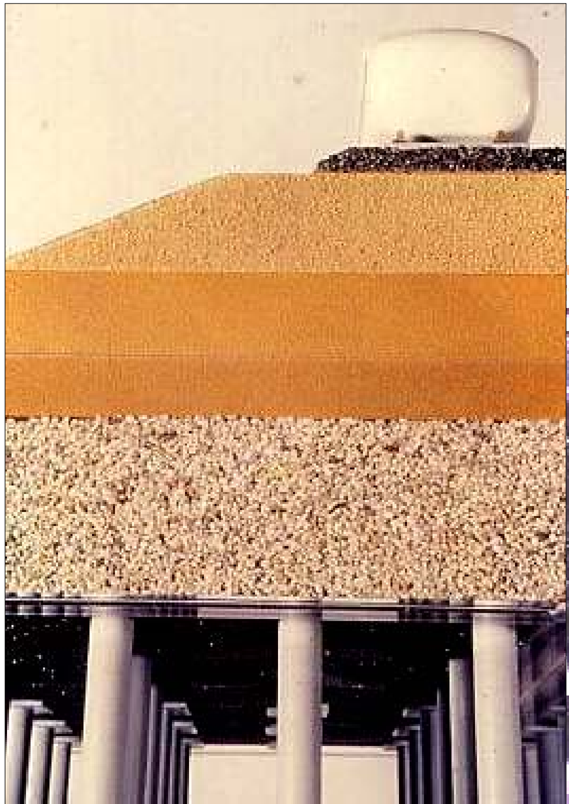
Gründung einer Bahnstrecke auf organischen Böden mit Tragsäulen im Mixed-In-Place-Verfahren (MIP) und einem geokunststoffbewehrten Tragschichtsystem

M. Raithel, W. Schwarz, M. Stadel

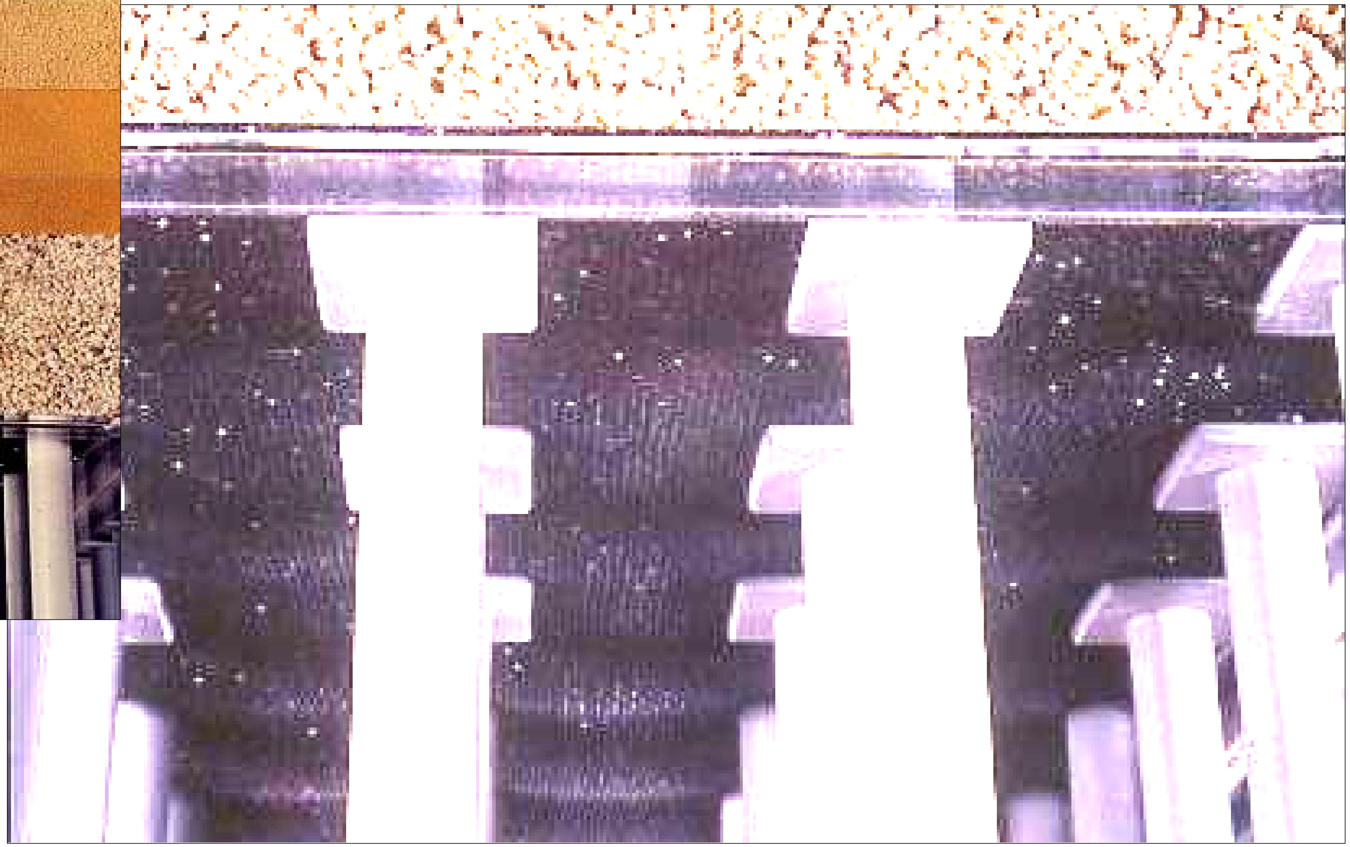
Foundation of a railway embankment on soft organic soils with Mixed-in-Place-columns and a geogrid reinforced load transfer mattress



Insight......membrane action etc

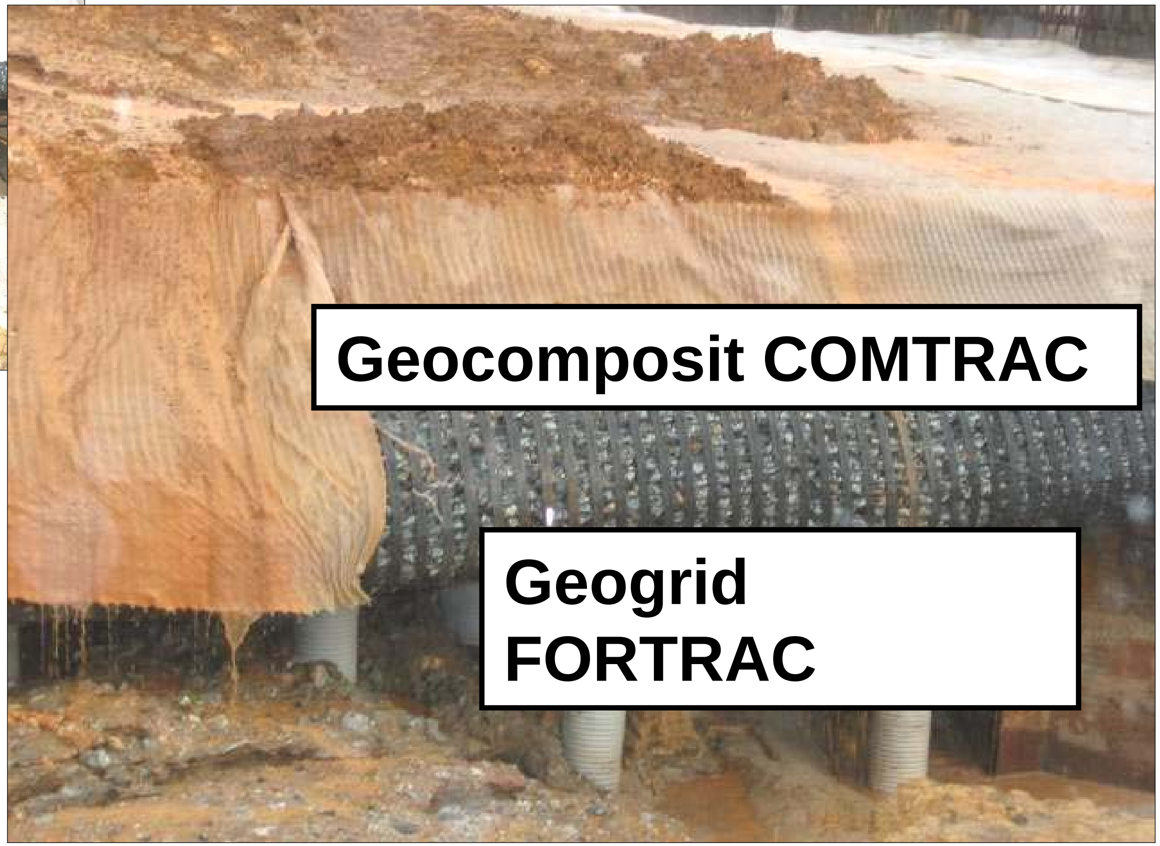


Model Alexiew 1996



Insight......membrane action etc

Reality 2003



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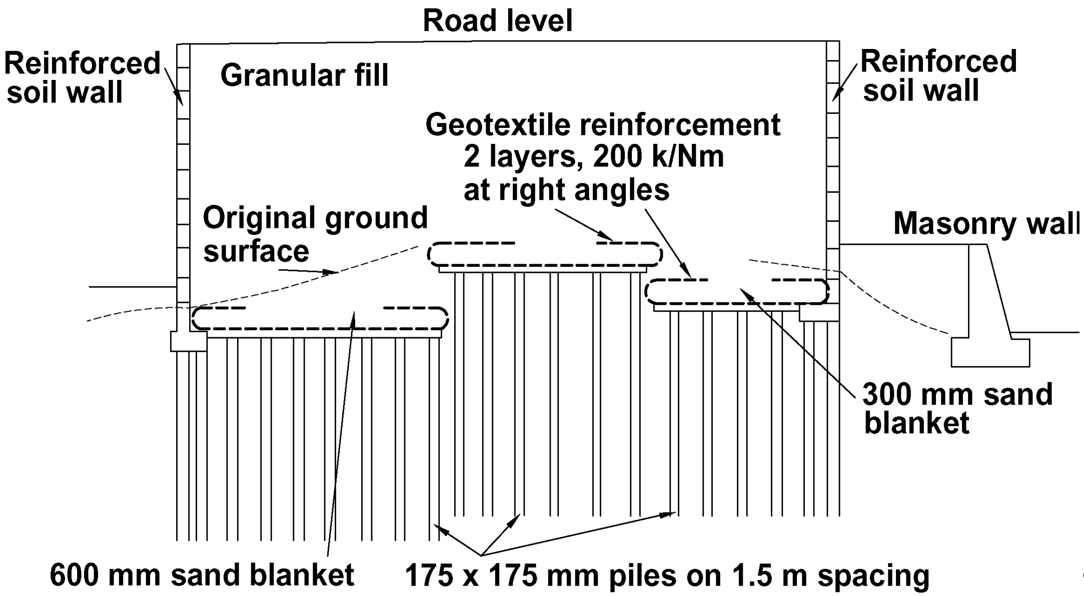
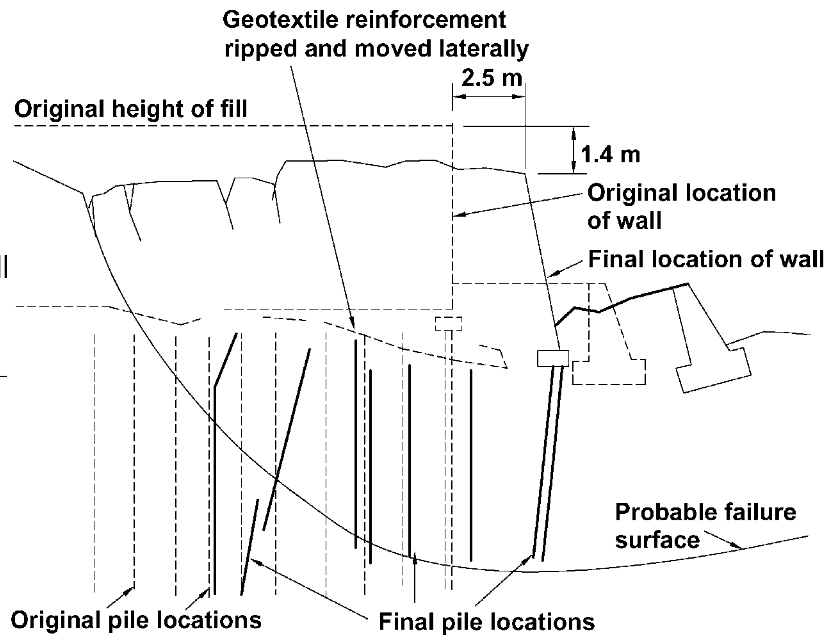
Insight......membrane action etc

Attention!! Results of inappropriate design...Example

Source:
Lawson C. R.,
Keynote
Lecture II, IS
Kyushu 2001



a) Reinforced piled embankment as designed



b) Failure of the reinforced piled embankment

Attention!! Results of inappropriate design...Example

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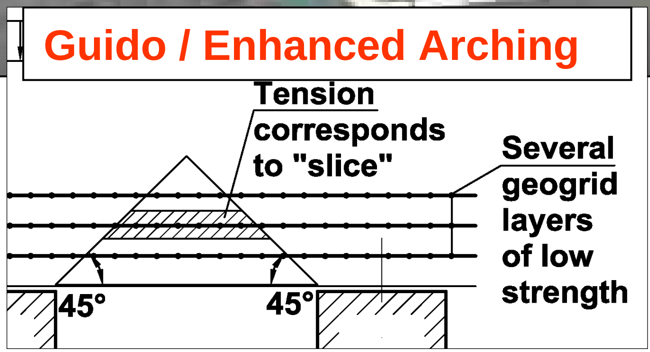
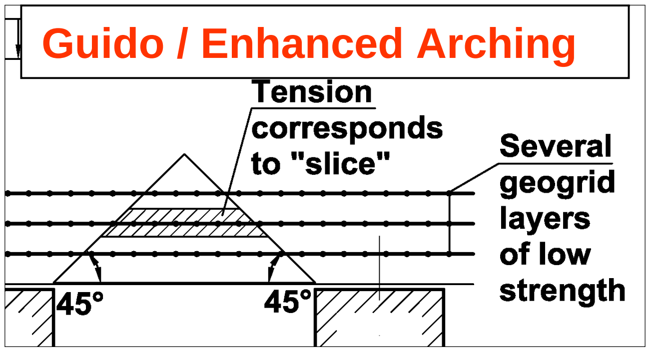
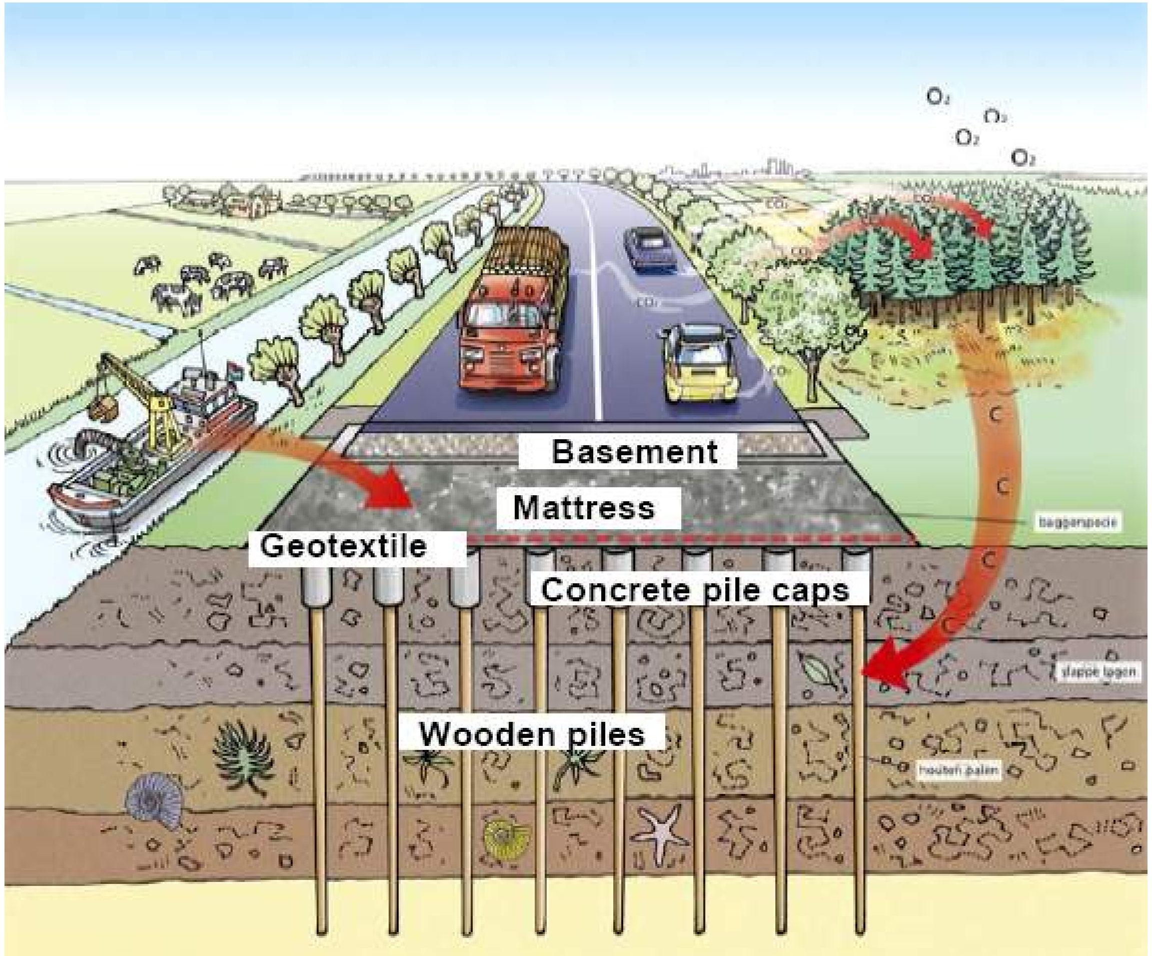
Attention!! Results of inappropriate design...Example



Attention!! Results of inappropriate design...Example



Tests Kyotoweg (Kyoto Road), NL, 2005-2006



www.houtenheipaal.nl

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www.huesker.com

GeoDelft

www.geodelft.nl

Suzanne van Eekelen

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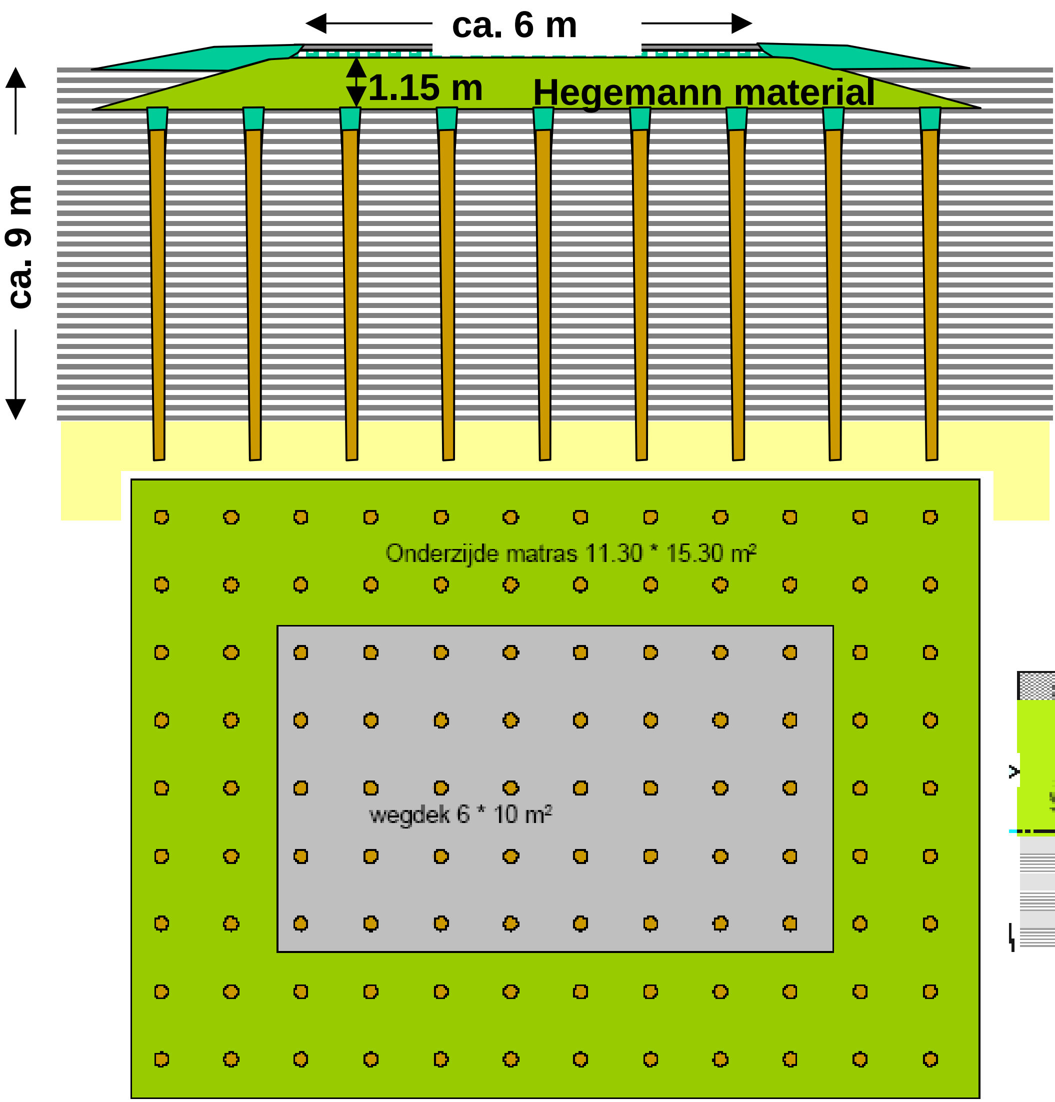
Geometry



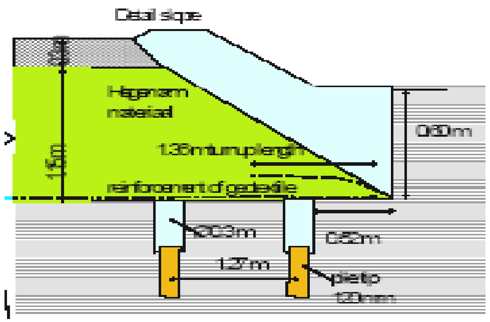
Ca. 8 m soft soil

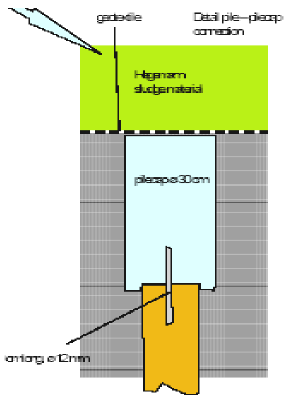
Wooden piles 120 mm

Pile Caps ø 0.30 m

CC distance piles 1.27 m

Height embankment ca. 1.15 m





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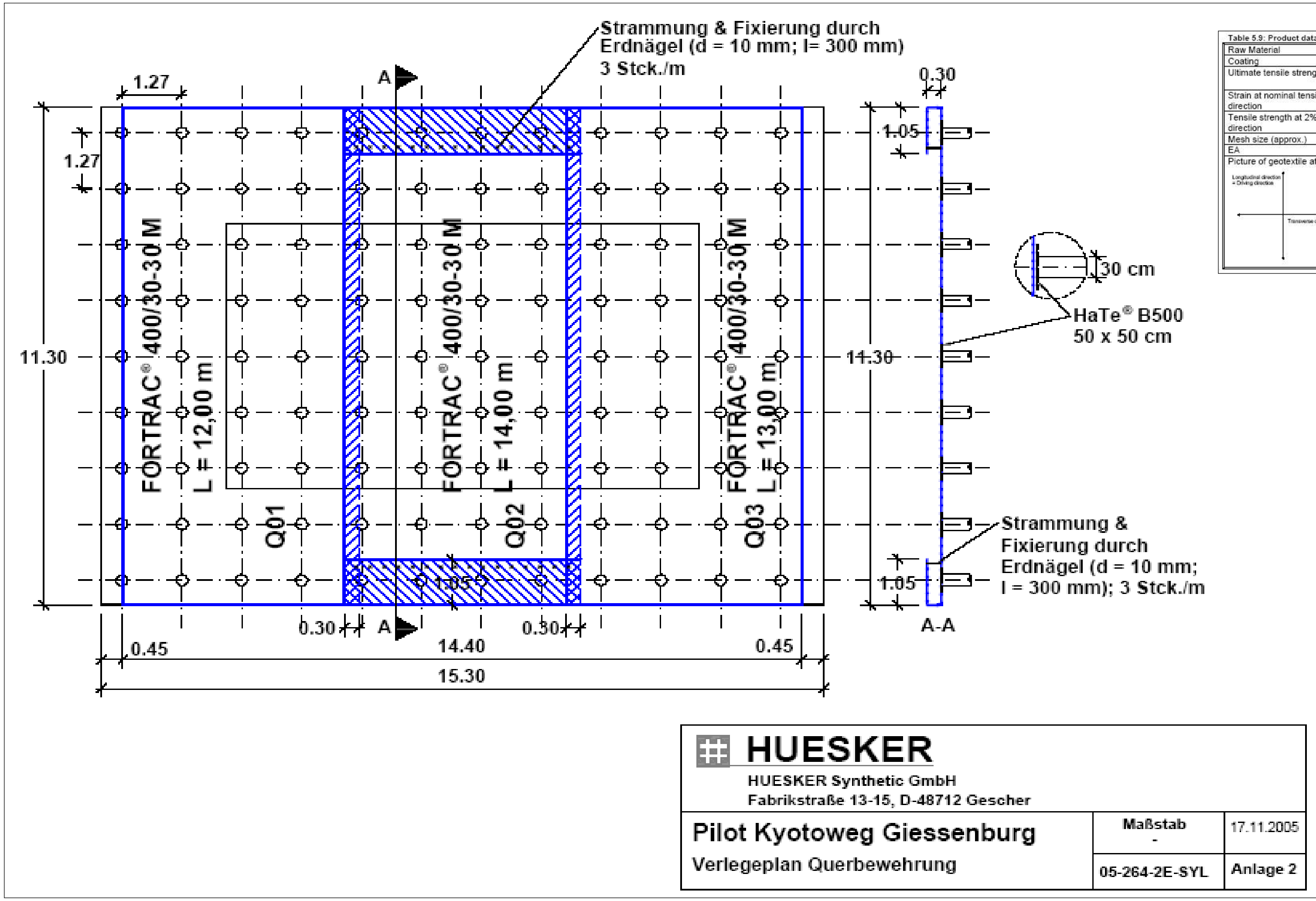
Reinforcement: Fortrac[R] 350 M & 400 M



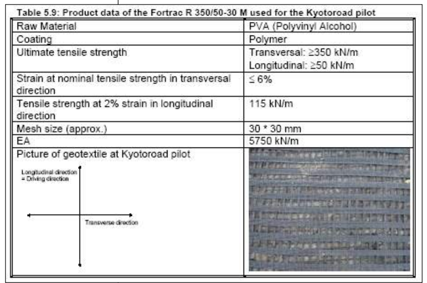


Table 5.9: Product data of the Fortrac R 350/50-30 M used for the Kyotoroad pilot

Raw Material	PVA (Polyvinyl Alcohol)
Coating	Polymer
Ultimate tensile strength	Transversal: ≥350 kN/m Longitudinal: ≥50 kN/m
Strain at nominal tensile strength in transversal direction	≤ 6%
Tensile strength at 2% strain in longitudinal direction	115 kN/m
Mesh size (approx.)	30 * 30 mm
EA	5750 kN/m
Picture of geotextile at Kyotoroad pilot Longitudinal direction = Driving direction Transverse direction	

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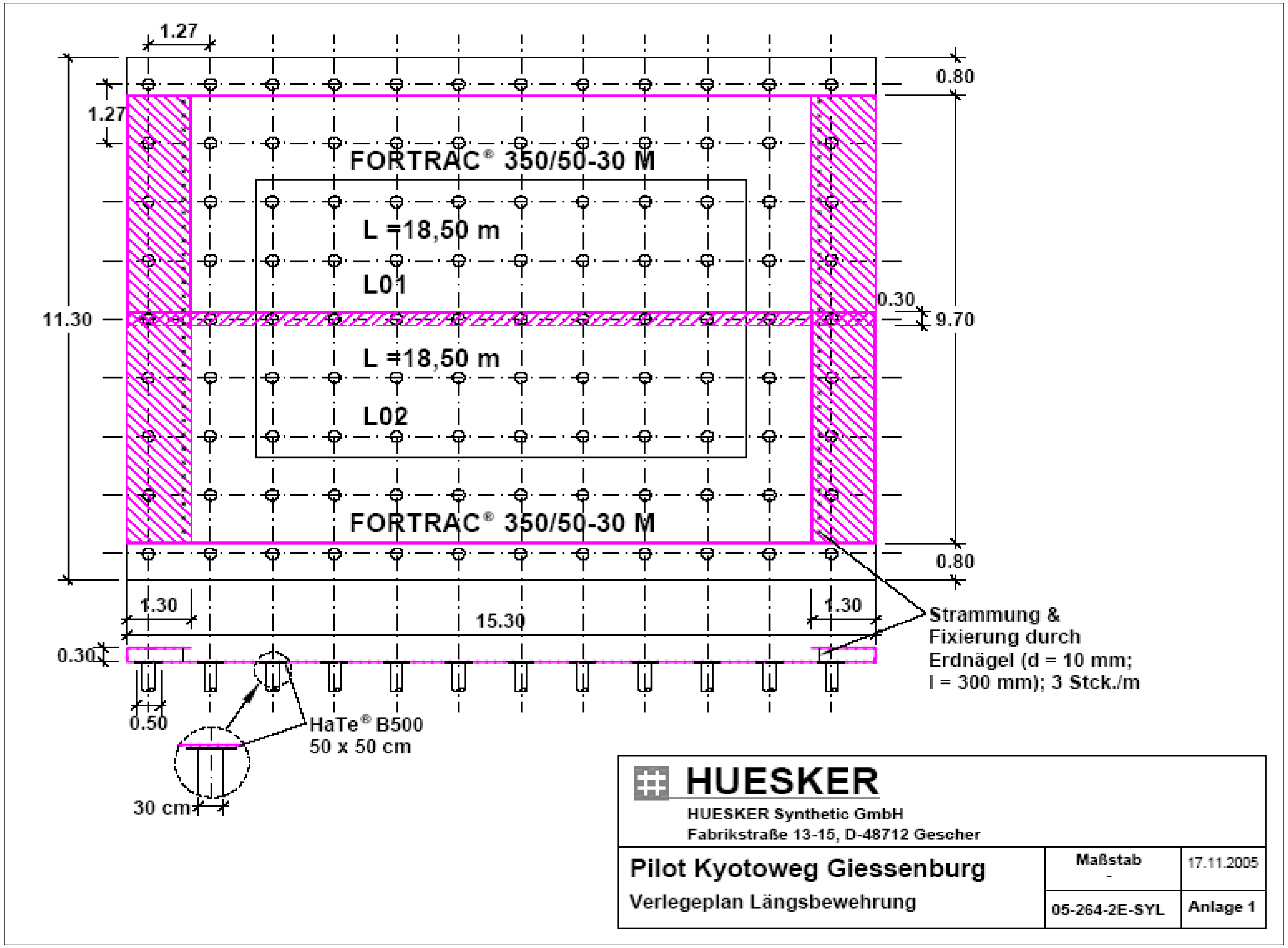
Reinforcement: Fortrac[R] 350 M & 400 M



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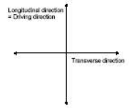
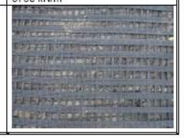
Picture of geotextile at Kyotoroad pilot 	

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Construction Nov 2005

Construction Nov 2005

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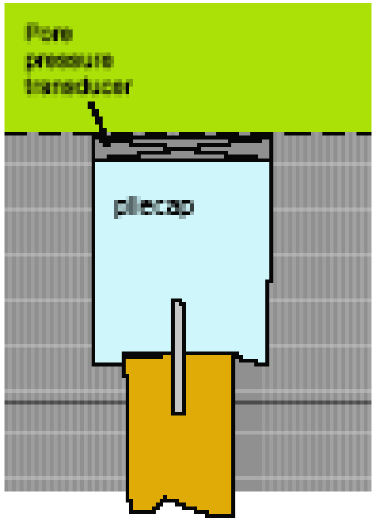
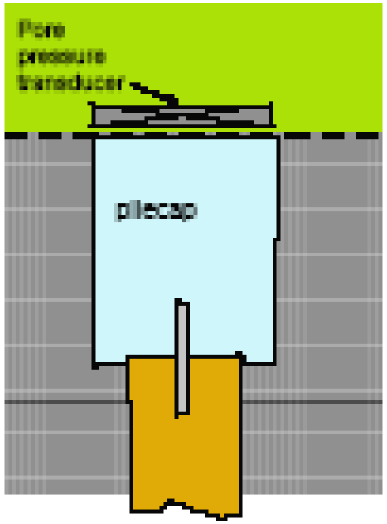
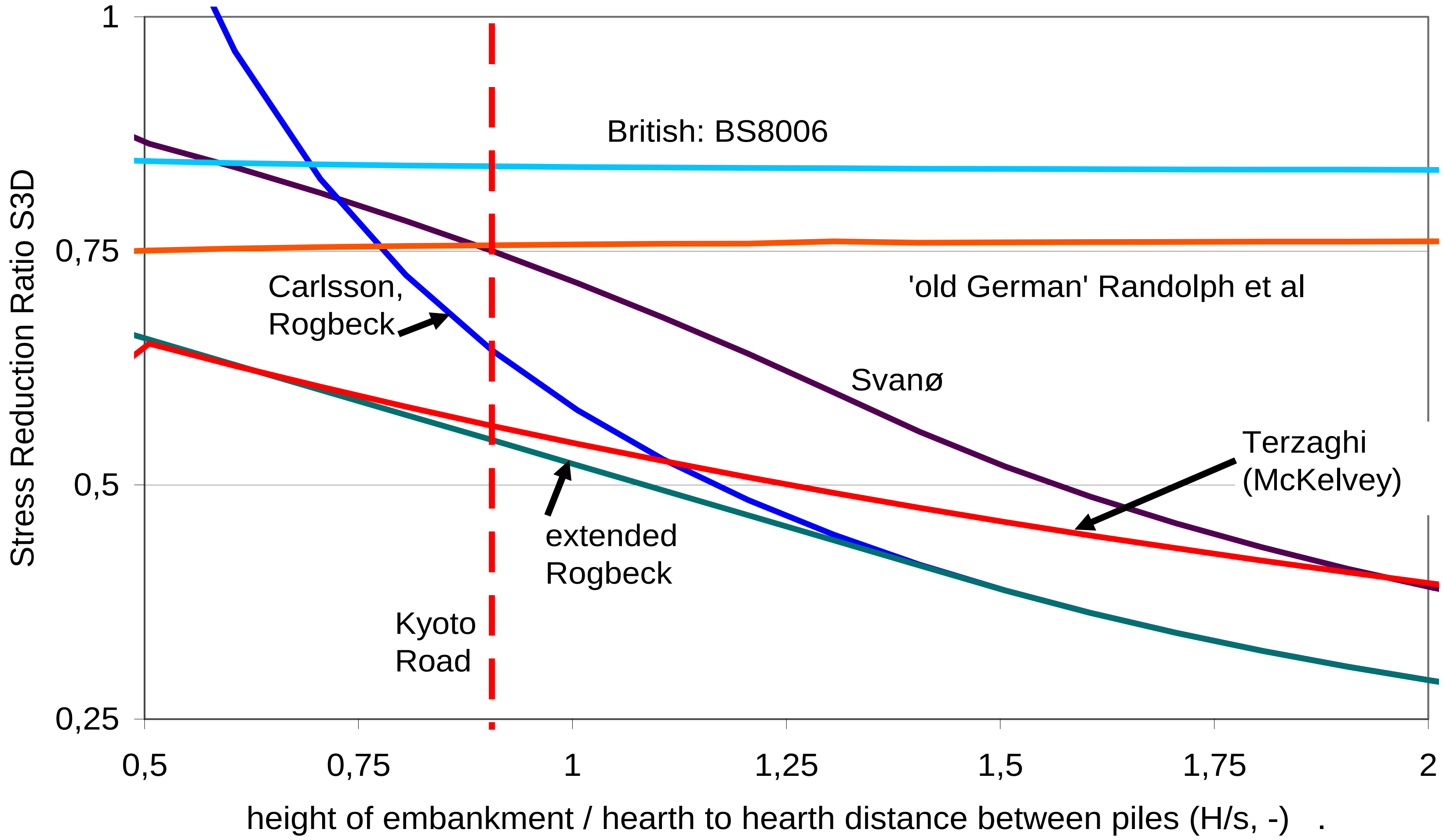
Measurements (part)

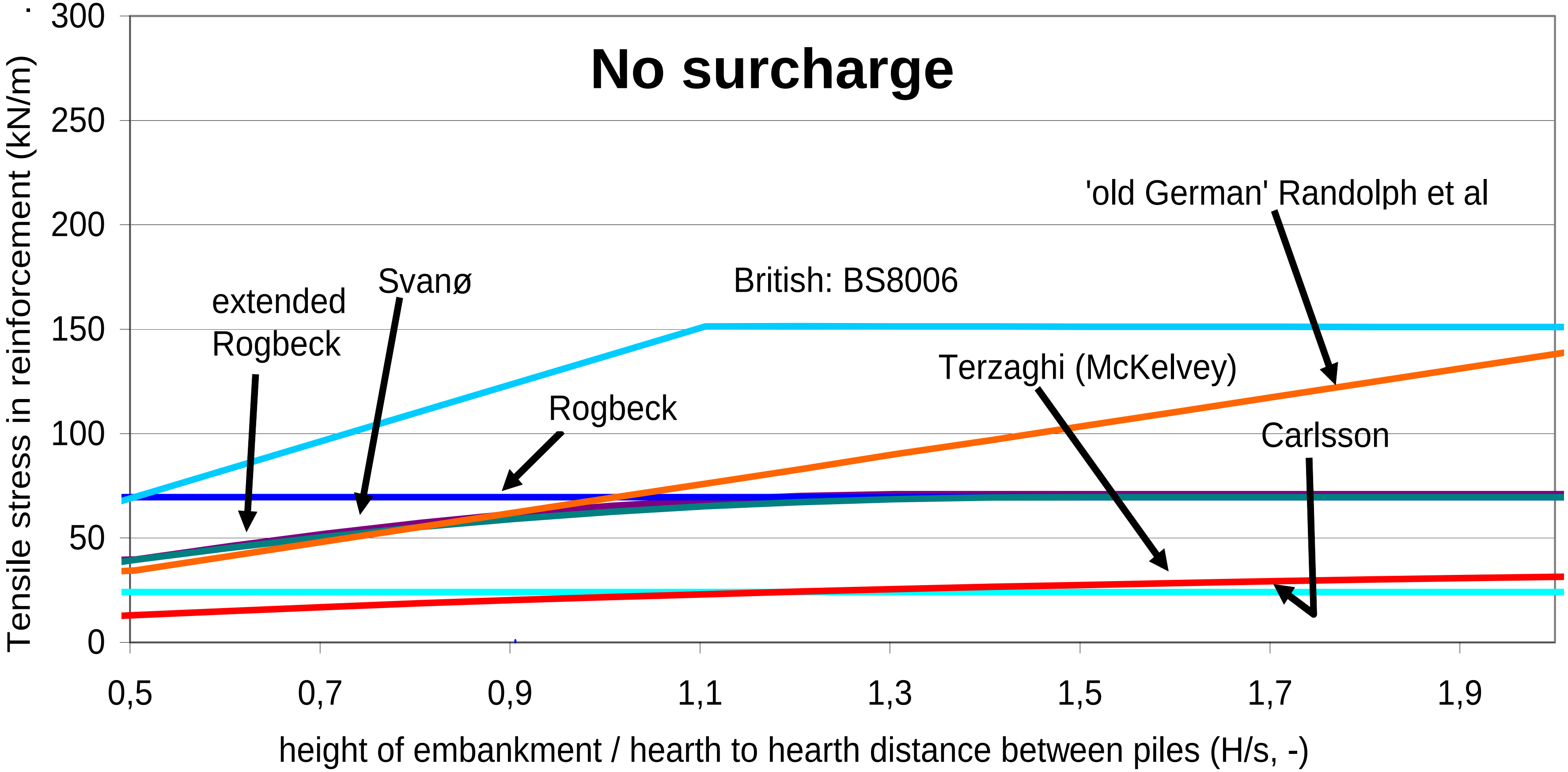




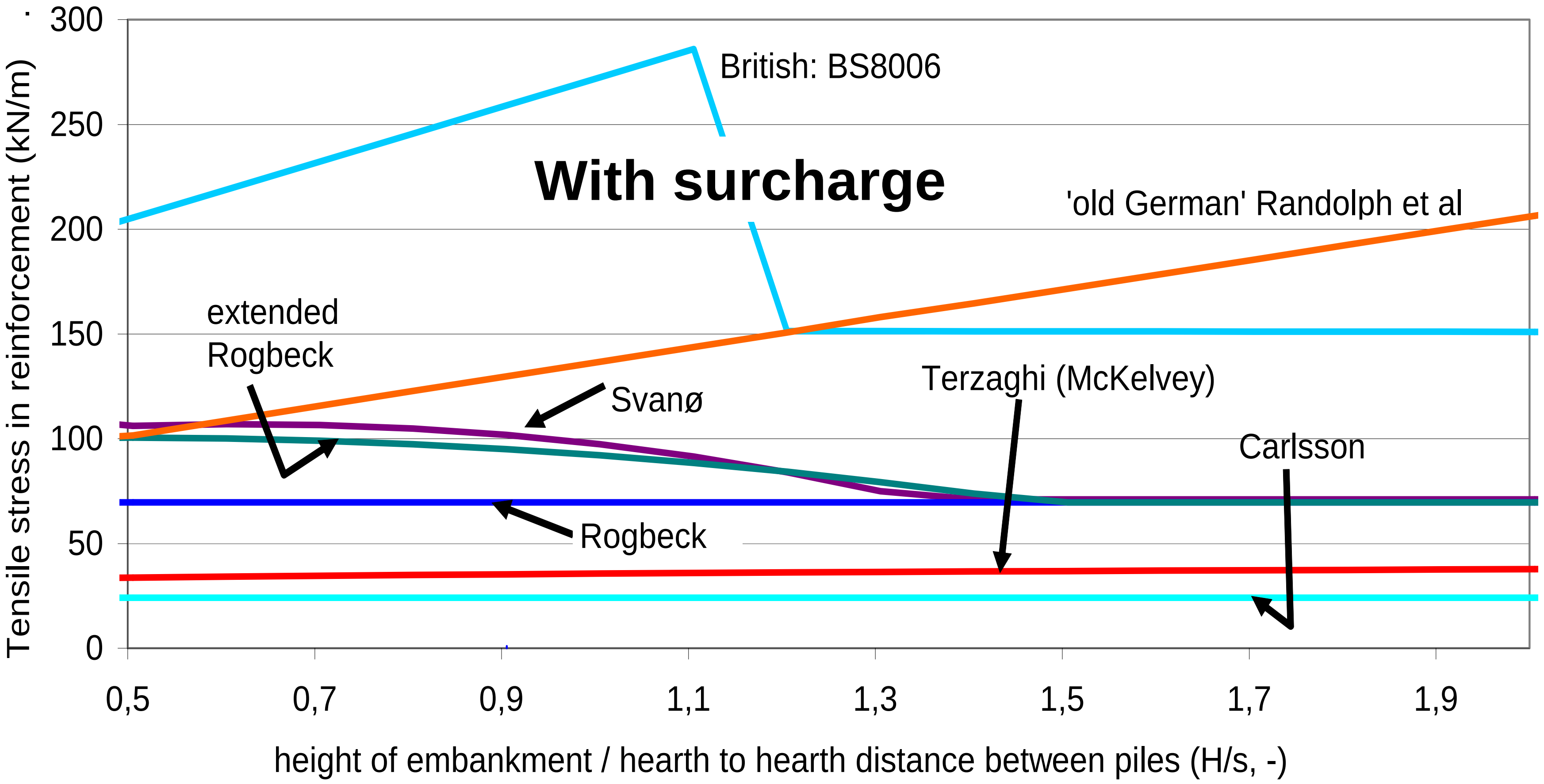
Comparison design procedures (vE)



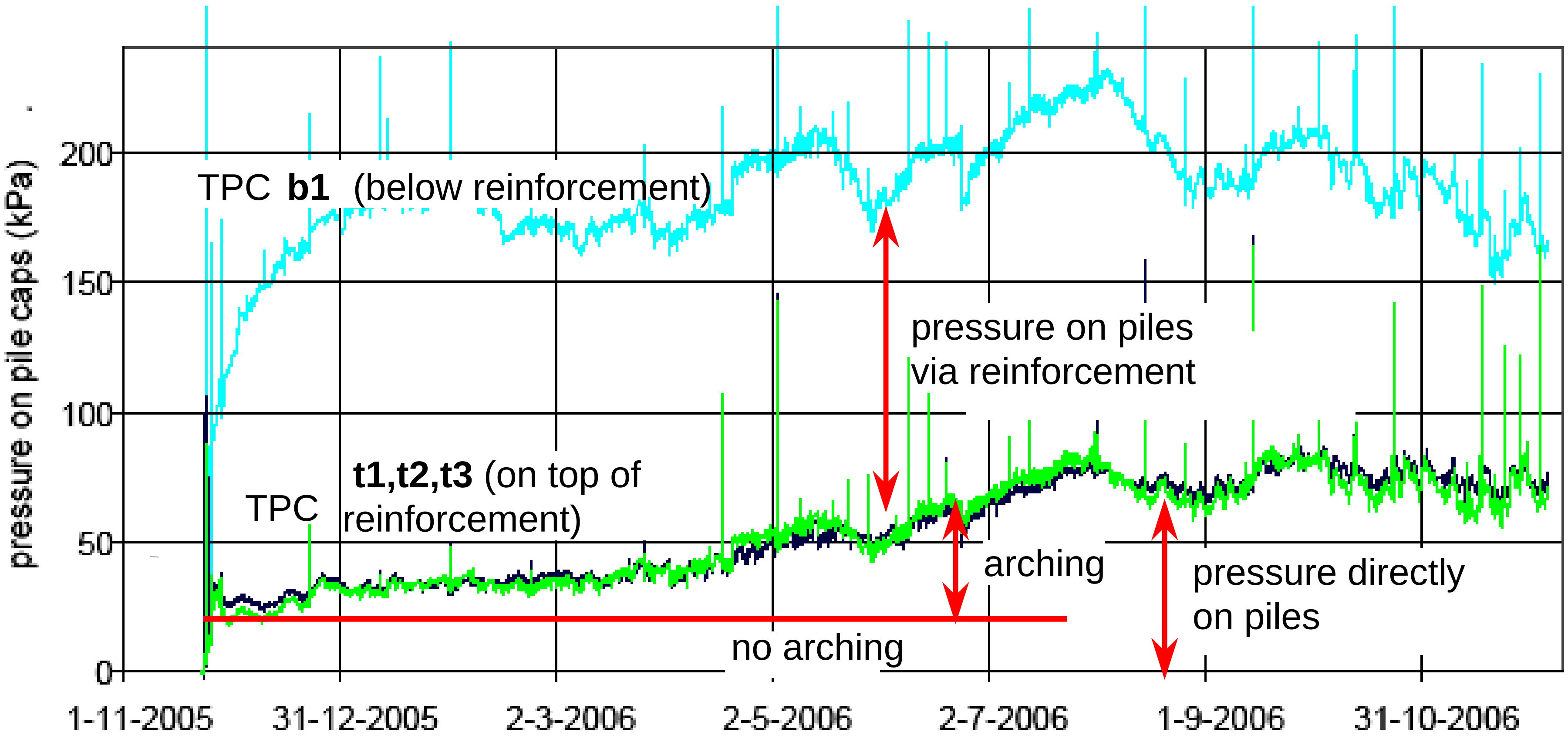
Comparison design procedures (vE)



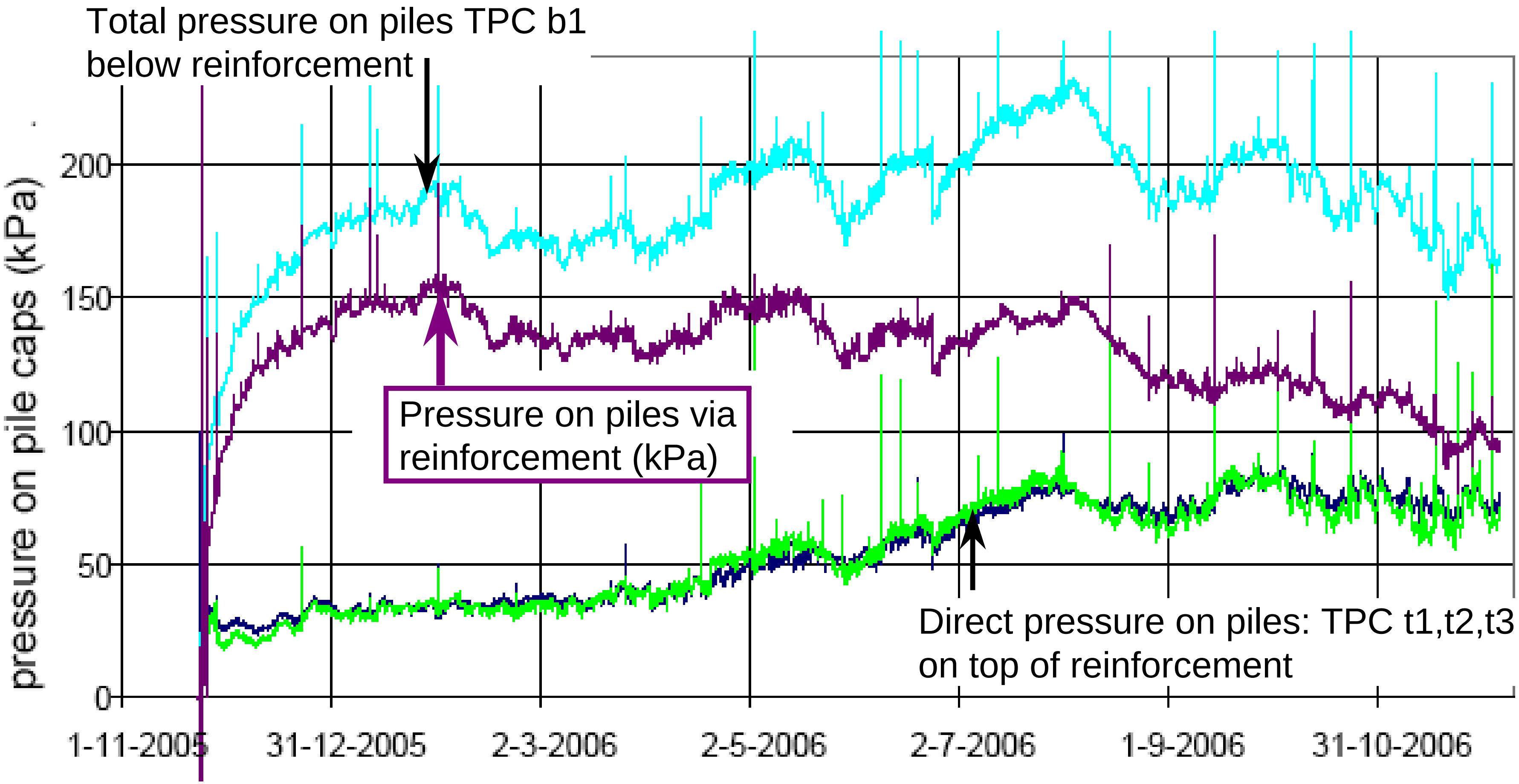
Comparison design procedures (vE)



Load distribution



Contribution of reinforcement



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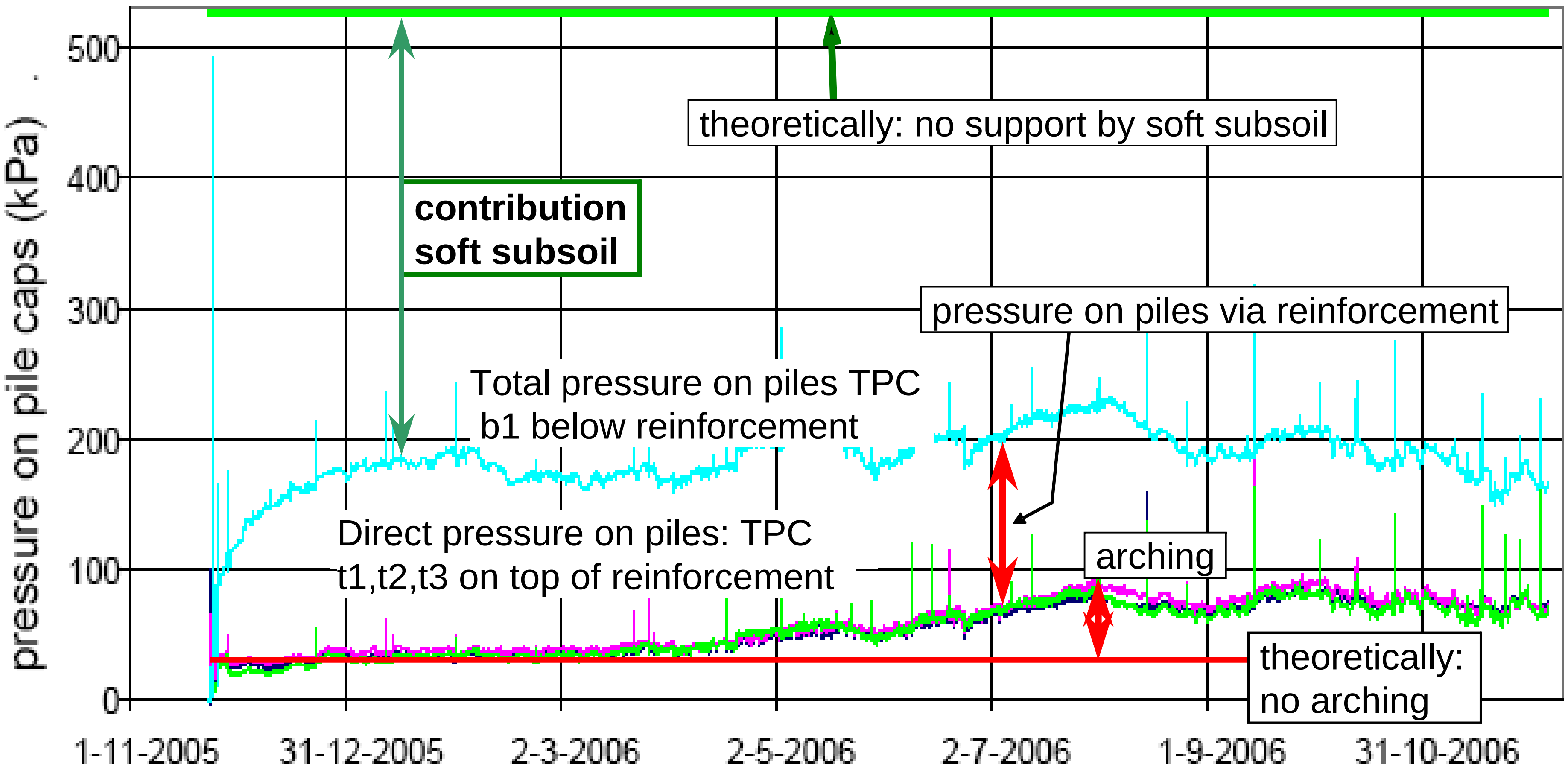
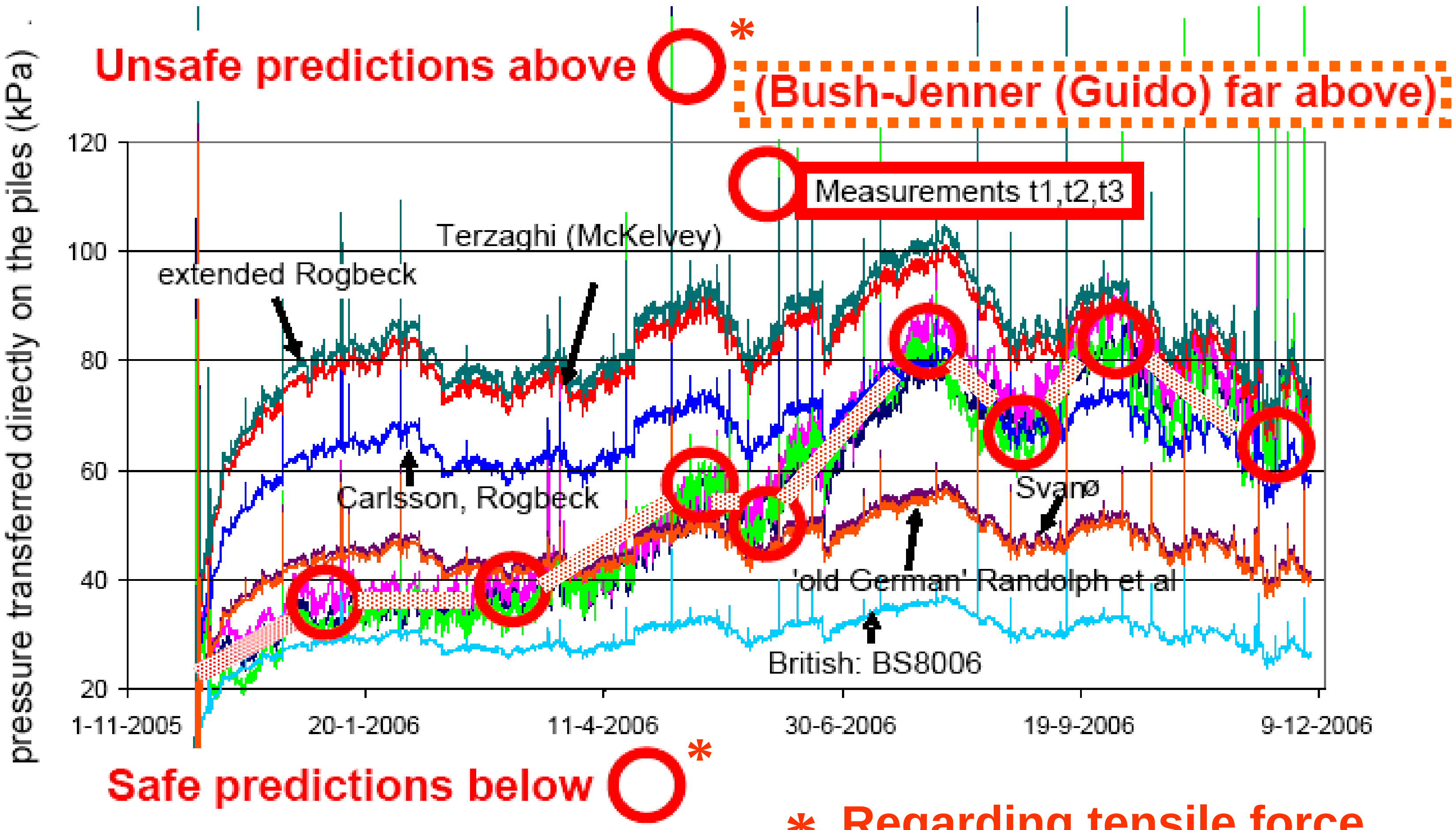
Contribution of soft subsoil



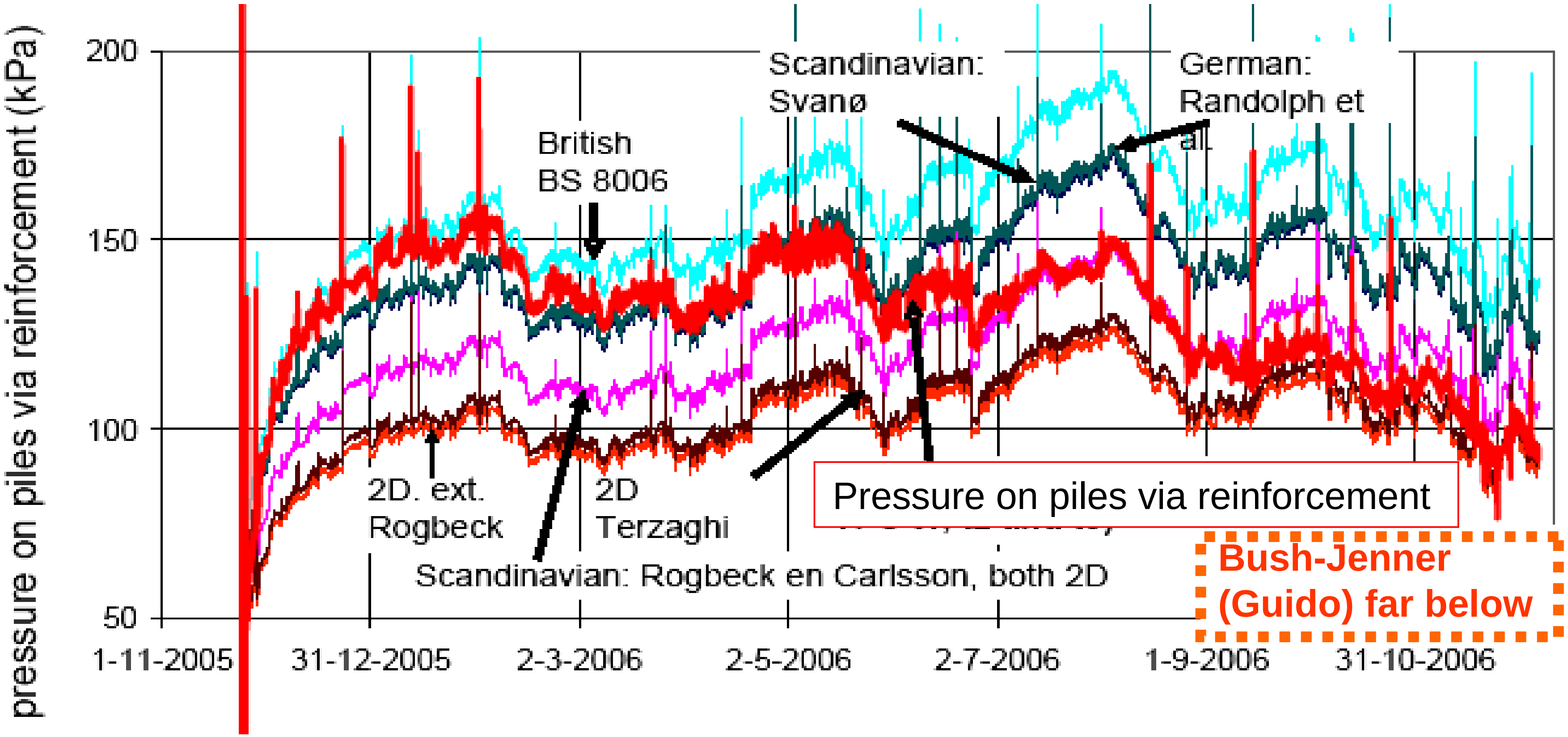
Comparison of calculations and measurements



* Regarding tensile force

Comparison of calculations and measurements

Safe predictions of tensile force: above red line



Unsafe predictions of tensile force: below red line

- **Counterpressure from soft subsoil ca. 50% or more in this case.**
- **Lower GWL in dry periods results in reduced counterpressure from soft subsoil provoking higher loads on reinforcement and piles.**
- **Dynamic loads reduce “arching”.**
- **Increase of “arching” over time due to some “cementation” of Hegemann-Sand in this case.**

Analytical models:

- **BS 8006 is most conservative.**
- **“Old German Method” based on Hewlett-Randolph less conservative, but mostly on the safe side.**
- **Rogbeck and Rogbeck mod (Skandinavia) and Terzaghi mostly unsafe.**
- **Bush-Jenner alias Guido very unsafe.**

Supported embankments

(on (softer) GEC columns)

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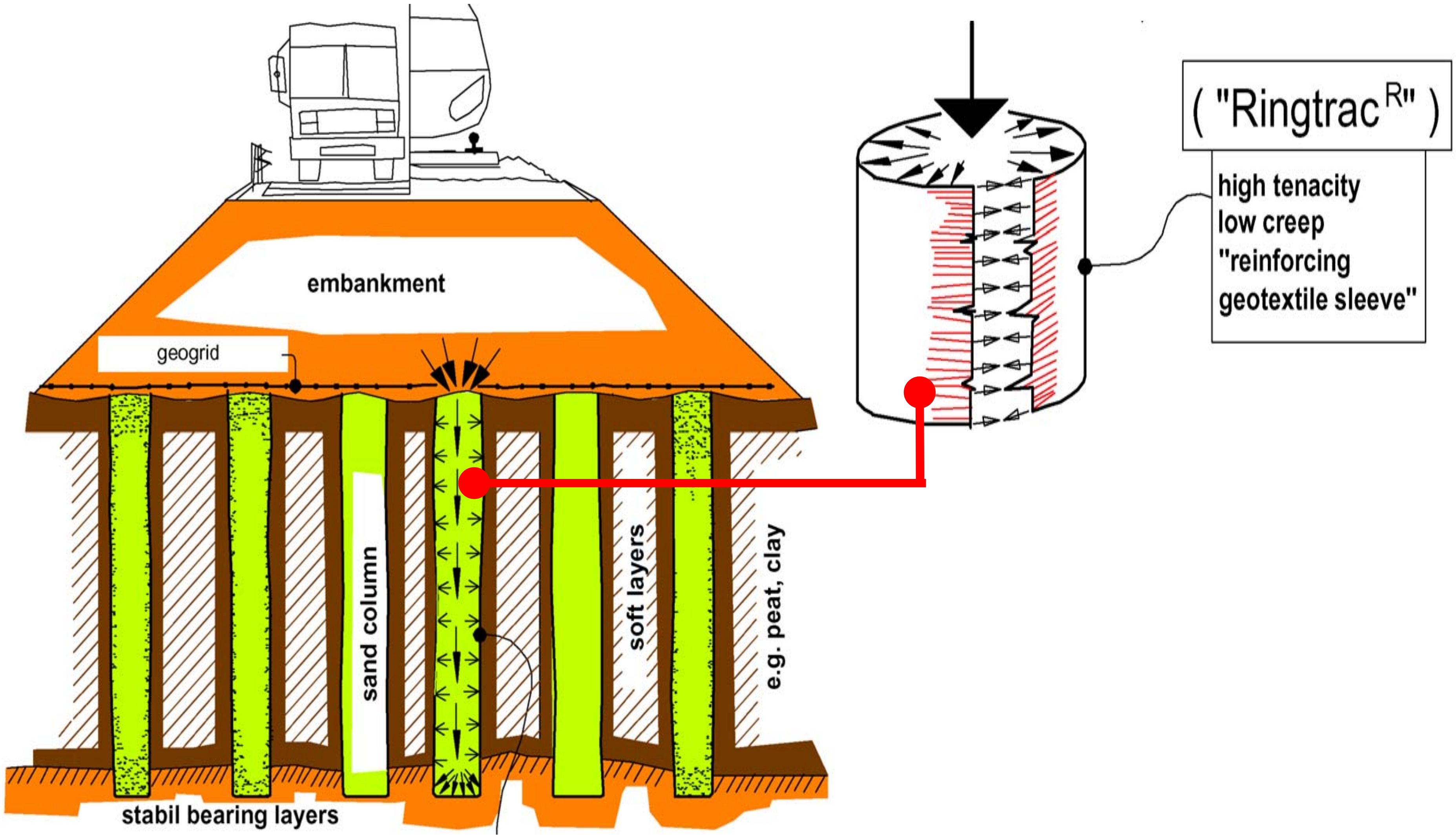
Geotextile Encased Columns (GEC): Main idea



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GEC: Main idea

1. Bearing, pile-similar elements.

Primary functions of geotextile:

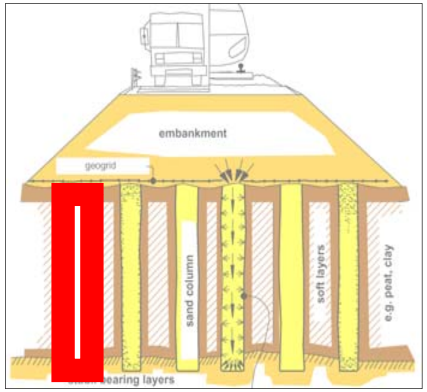
- <u>reinforcement</u> (controlled confinement)
- separation

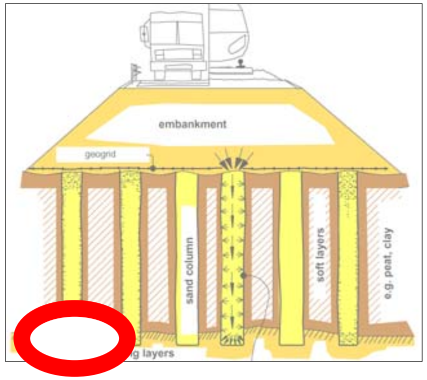
Secondary function :

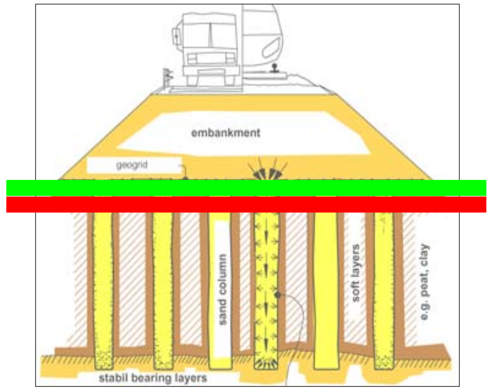
- filtration

2. End-bearing type.

3. Not settlement-free; more compressible than e.g. steel or RC-piles; <u>but most settlements during construction time.</u>





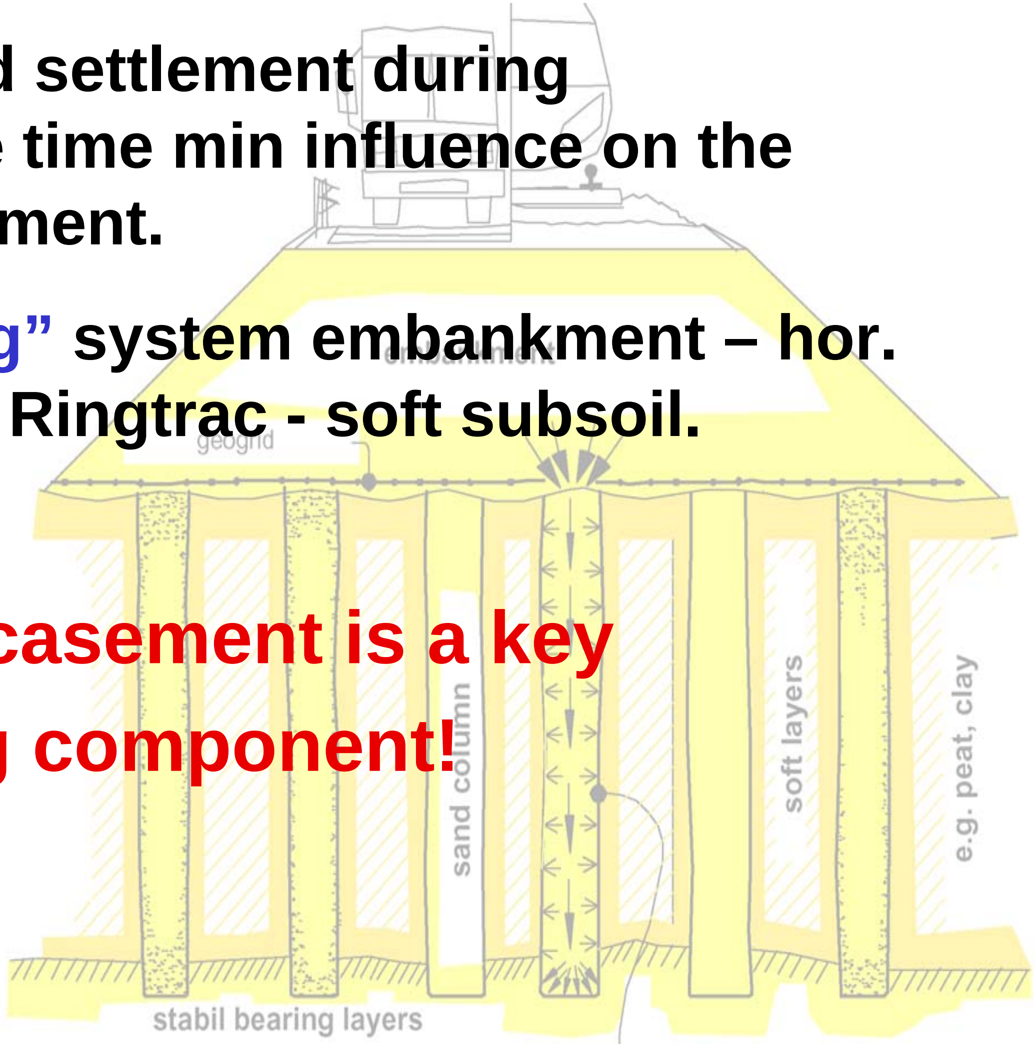


GEC: Main idea

4. Permeable: accelerated settlement during construction, at the same time min influence on the natural hydraulic environment.

5. Ductile, "self-regulating" system embankment – hor. reinforcement (geogrid) - Ringtrac - soft subsoil.

<u>Note:</u> The encasement is a key bearing component!



GEC: Main idea

Geotextile encasement:

- **In soft soils:**

  higher bearing capacity
  reduced settlement

- **In very soft soils:**

  the only possibility

1. **For the vertical loads:**
   A. **Raithel:** **Analytical, iterative, stress-strain-related, commonly used with good success**
   B. **Van Impe:** **older, not strain-related**
   C. **Numerical analyses also possible, but not definitely better…**

2. **For the global stability:**
   A. **Analytical, e. g. Bishop under consideration of columns fill and Ringtrac^{R}'s resistance**
   B. **Numerical, see above**

Soil Improvement Techniques and their Evolution

By
W.F. VAN IMPE
Soil Mechanical Department, Ghent State University

A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1989

not strain-related

Schriftenreihe Geotechnik
Universität Gh Kassel

D. Alexiew
08/99

Herausgeber:
Univ.-Prof. Dr.-Ing. H.-G. Kempfert

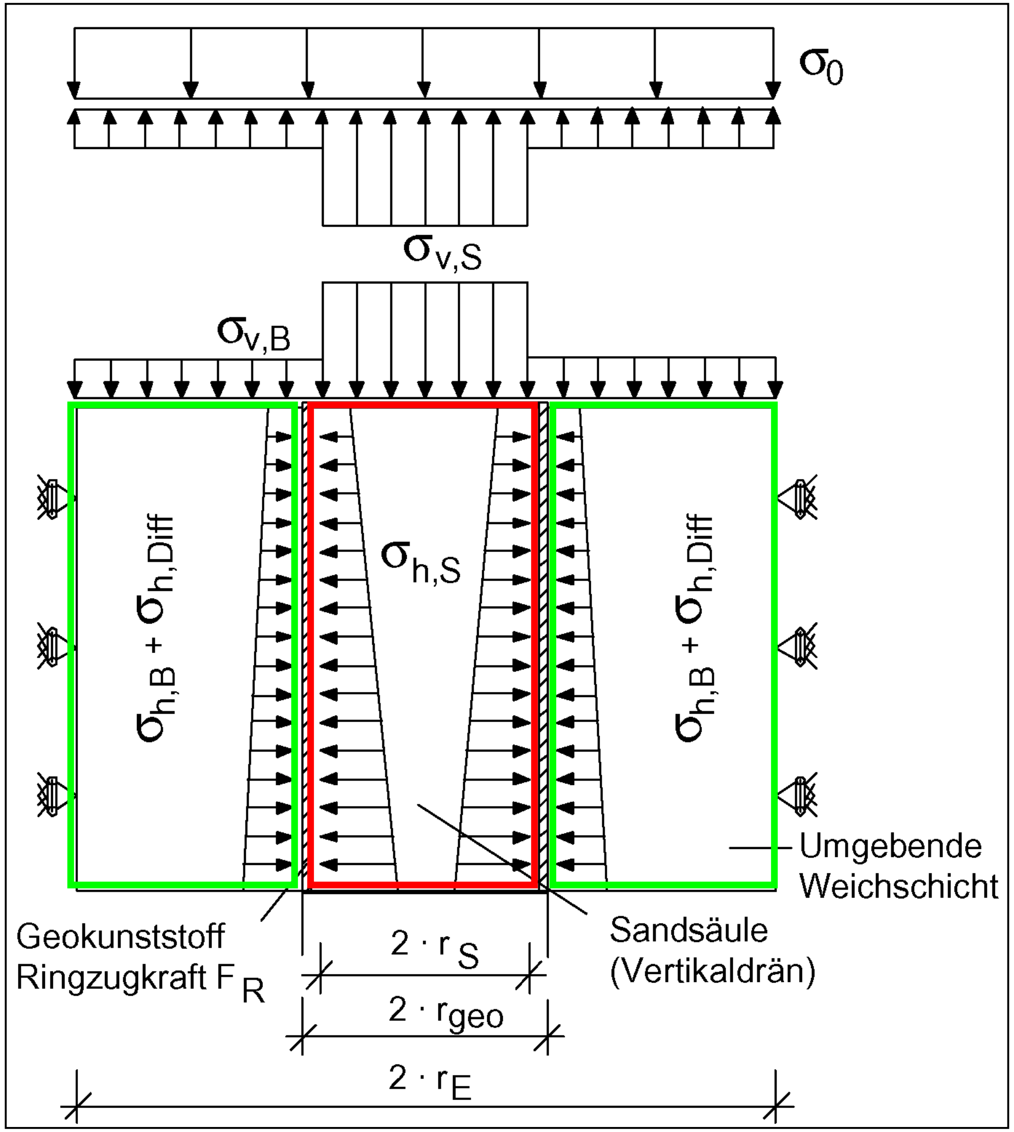
Zum Trag- und Verformungsverhalten von geokunststoffummantelten Sandsäulen

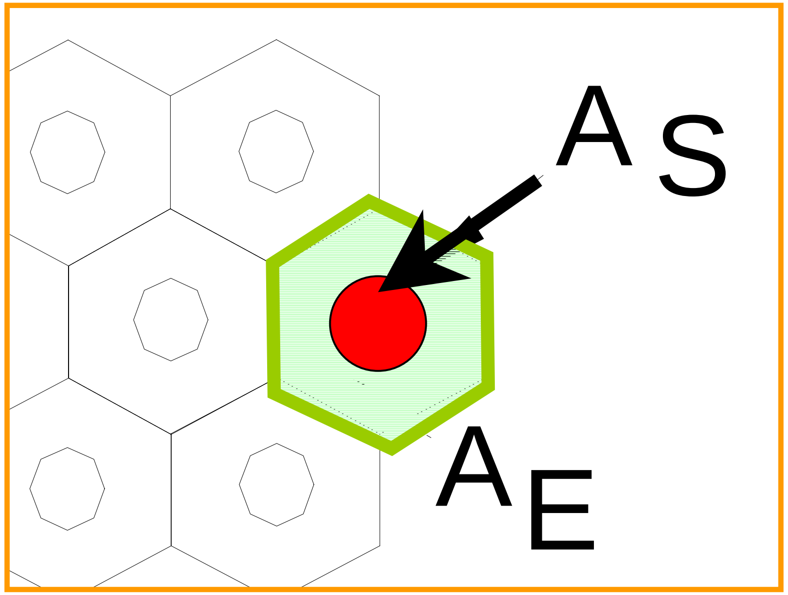
Heft 6

Juli 1999

strain-related

German EBGEO 2007 Draft 6.10





Based on the unit area approach

It is a typical interactive system!!!

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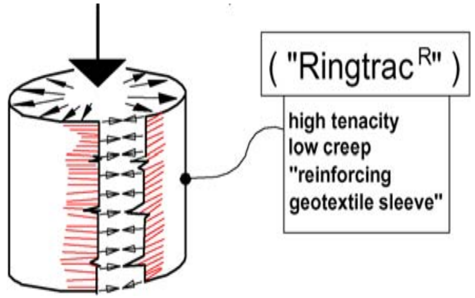


- quick mobilization of radial support
- typically only 2 to 4 % ring-strain allowed

settlements

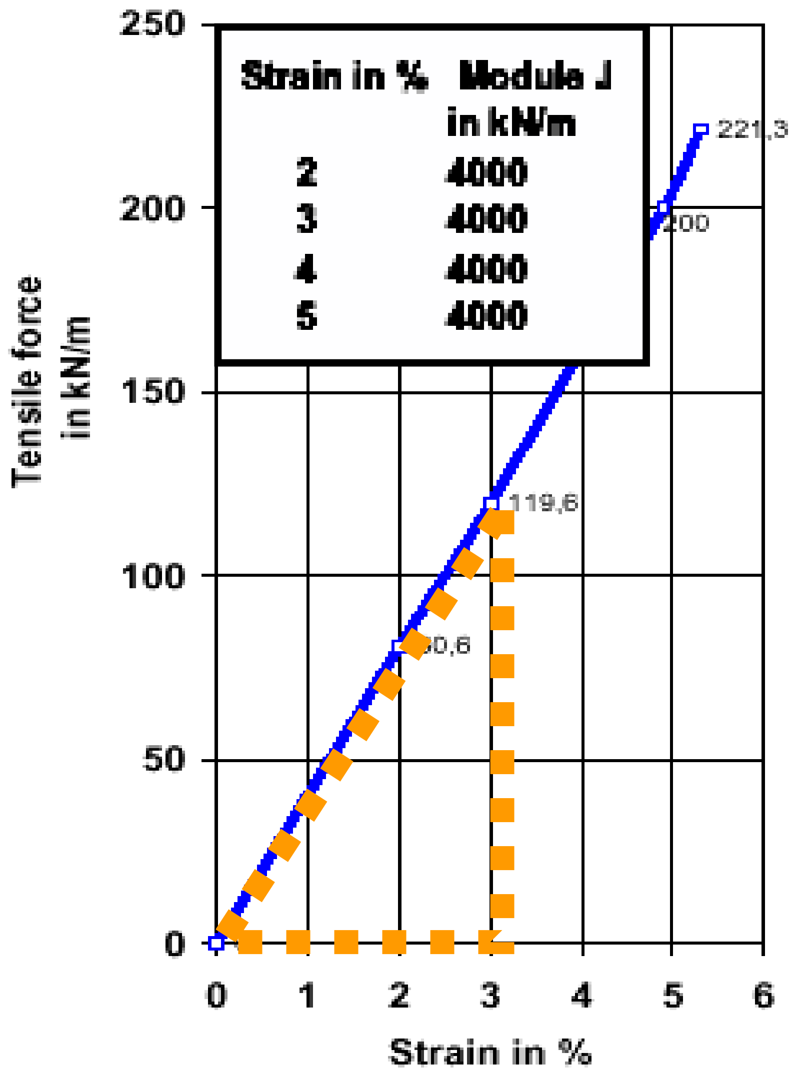
high short- and long-term ring tensile stiffness (modulus J) needed

Mixed ULS / SLS-design!
Rare!

- sufficient bearing capacity

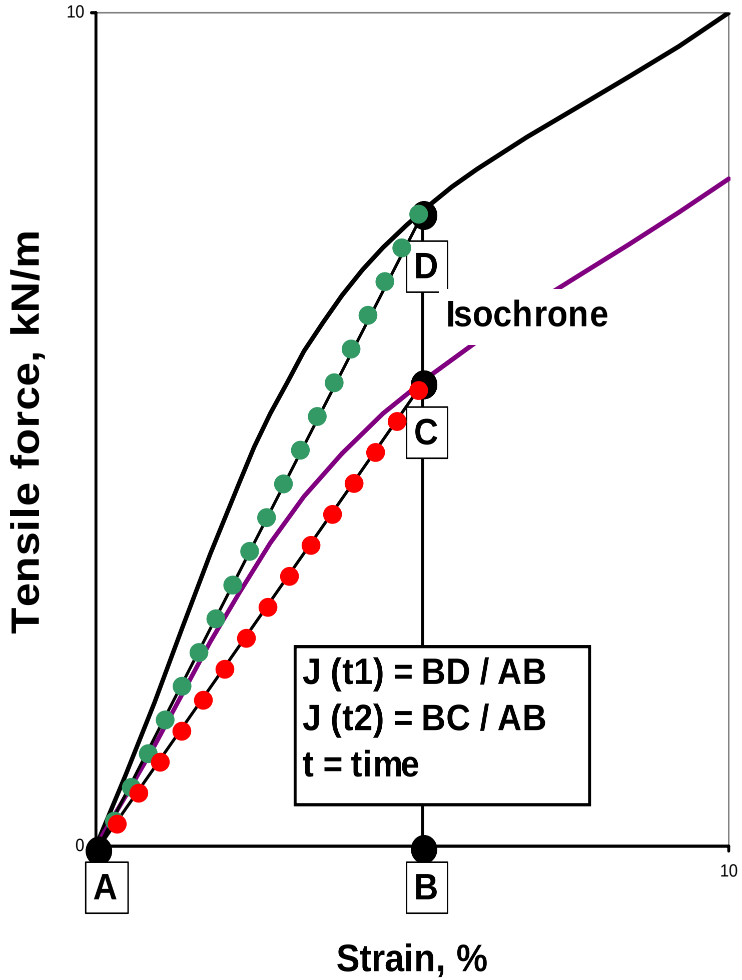
high ring design strength needed

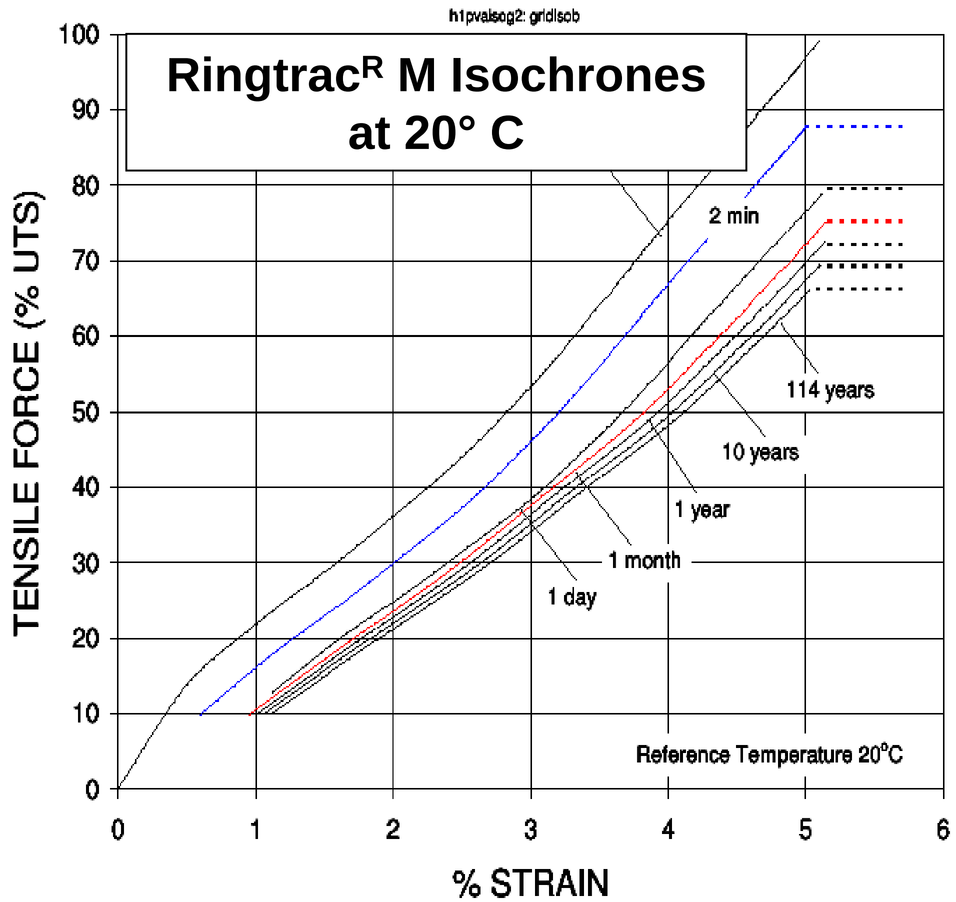
Ring modulus J (short - term)



But attention: Creep!!!

Ring modulus J (long - term)

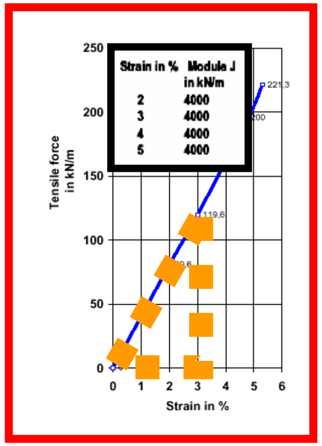




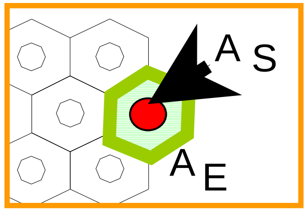
Design Options

- **Reduce the deformability of GEC:**
  - **- higher quality fill (e.g. gravel instead of sand)**

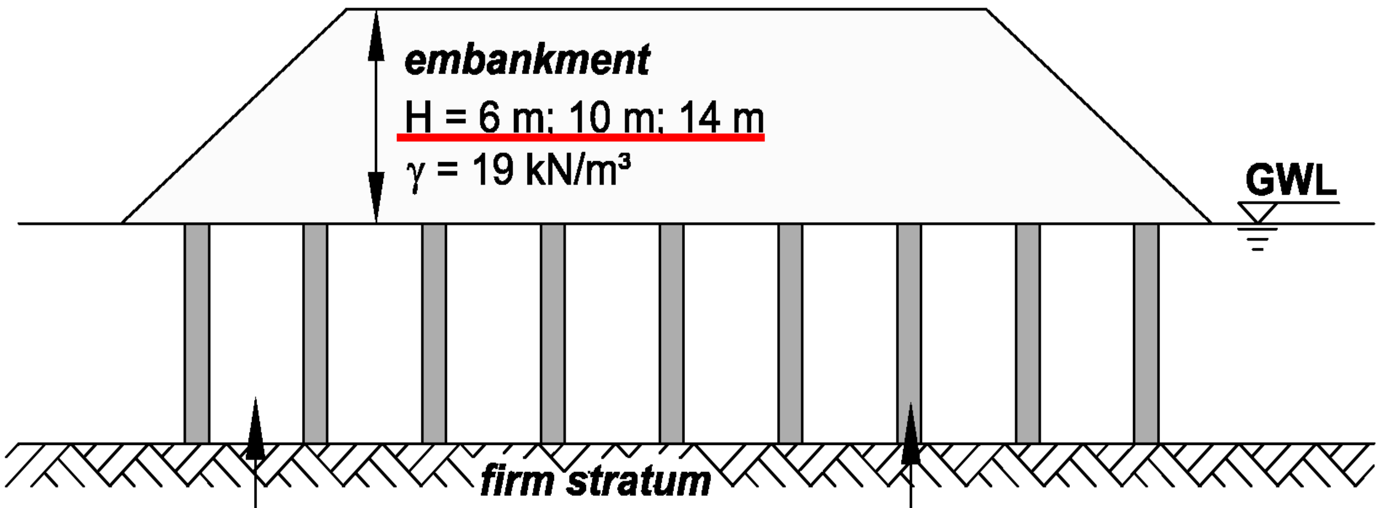
  - higher ring tensile stiffness J
  from the wide range of Ringtrac
  (USUALLY THE BEST SOLUTION)



- **More columns per unit area**
  (typically 10 % to 20 % relative GEC area)



- **Increase column diameter**



soft soil

thickness of the soft soil layer	10 m
submerged unit weight	$\gamma' = 7$ kN/m³
effective shear parameters	$\varphi' = 25°$ $c' = 10$ kN/m²
oedometric (constrained) module	$M_{ref} = 0.5$ MPa; 1.0 MPa
Poissons ratio	$\nu = 0.4$

GEC columns

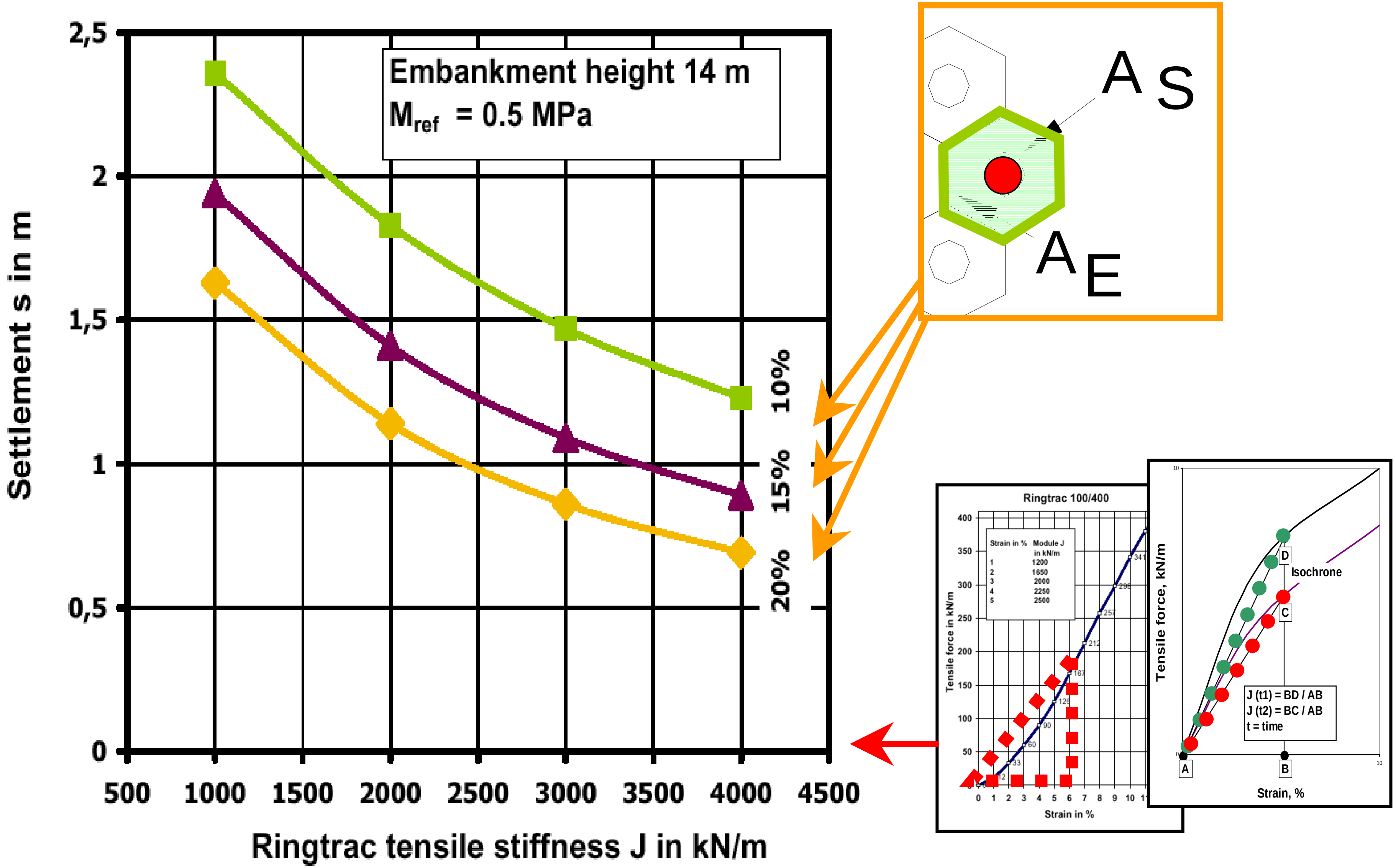
$D_{Ringtrac} = D_{steel\ pipe} = 0.8$ m

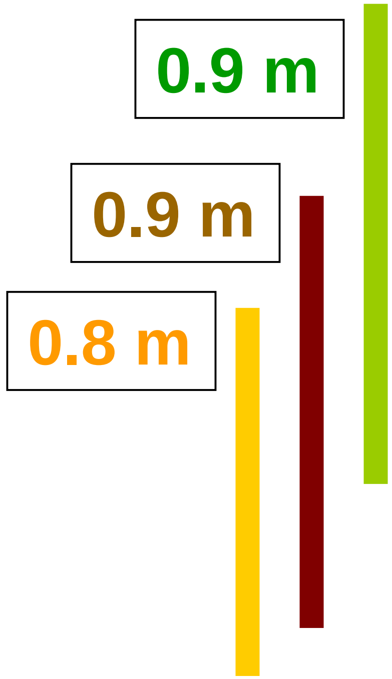
fill material of GEC

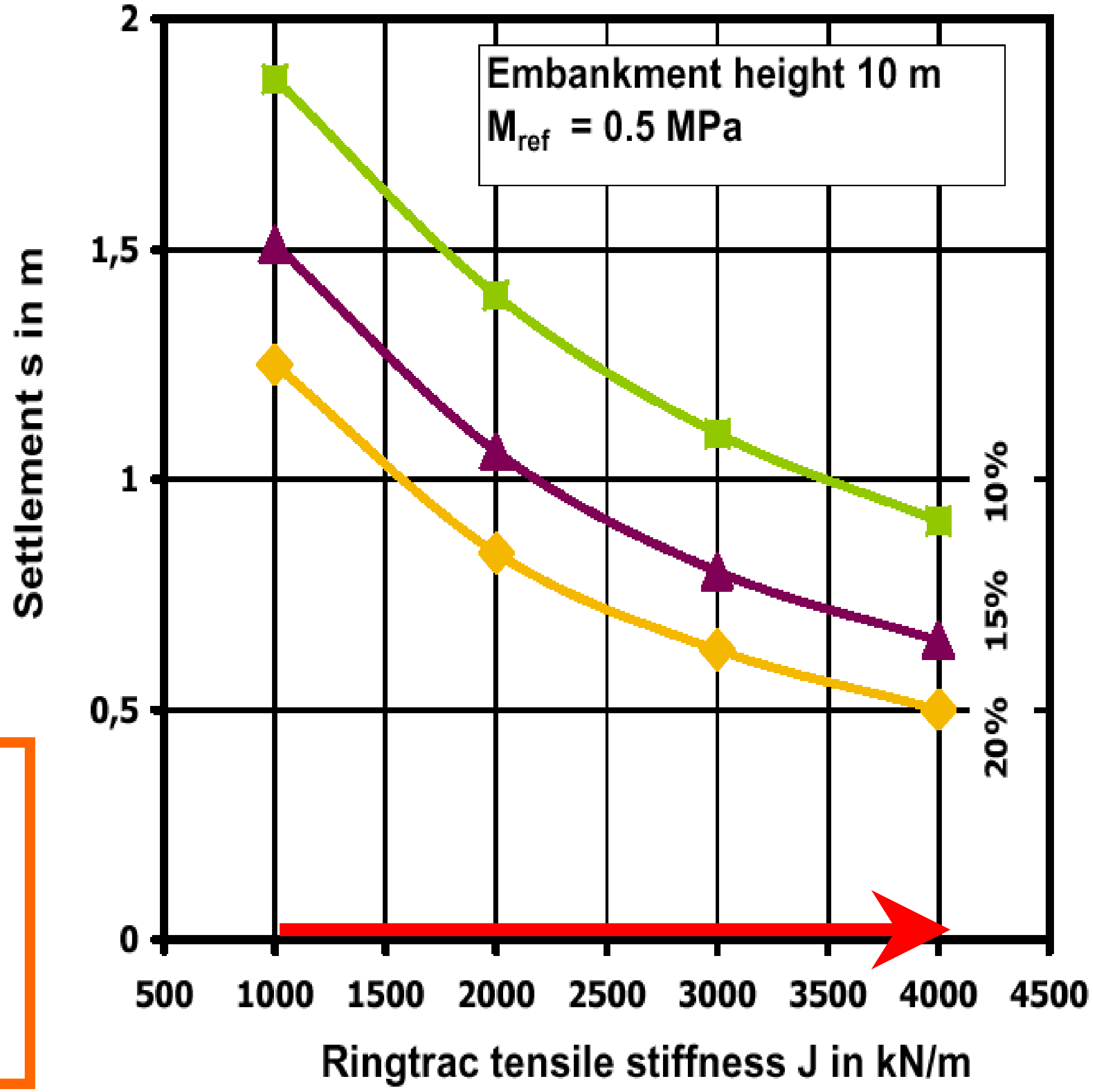
$\gamma' = 9$ kN/m³ submerged unit weight

$\varphi' = 30°$, $c' = 0$ kN/m² effective shear parameters

$J_{Ringtrac}$ = 1000 to 4000 kN/m


Embankment height 14 m
M_ref = 0.5 MPa
Settlement s in m
2,5
2
1,5
1
0,5
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Ringtrac tensile stiffness J in kN/m
10%
15%
20%
A S
A E
Ringtrac 100/400
Tensile force in kN/m
Strain in %
Strain in %
Module J in kN/m
Tensile force, kN/m
Strain, %
Isochrone
D
C
A
B
J (t1) = BD / AB
J (t2) = BC / AB
t = time





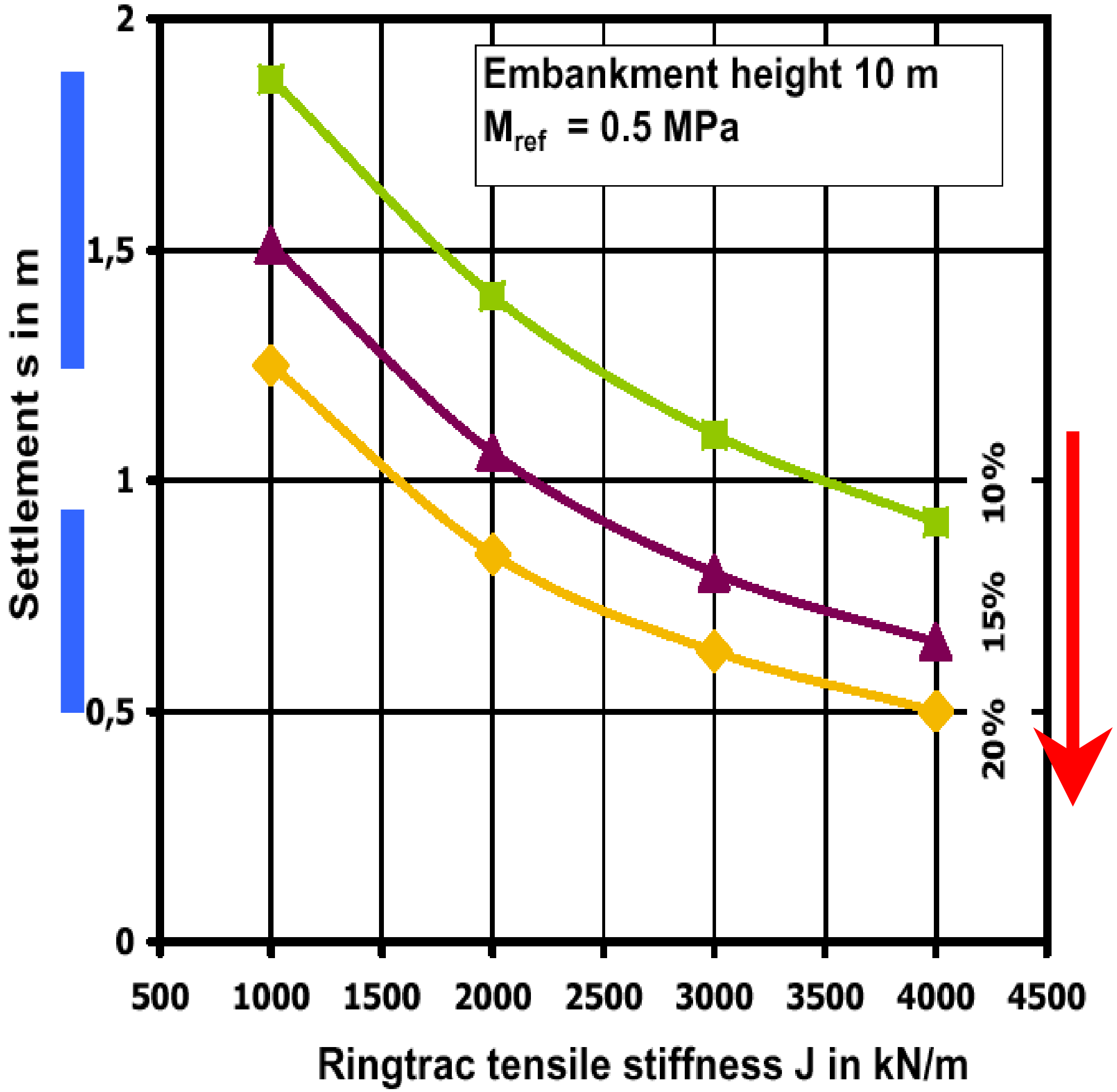
Settlement reduction

ca. 1 m due to higher ring modulus J

for all "%"

0.5 m

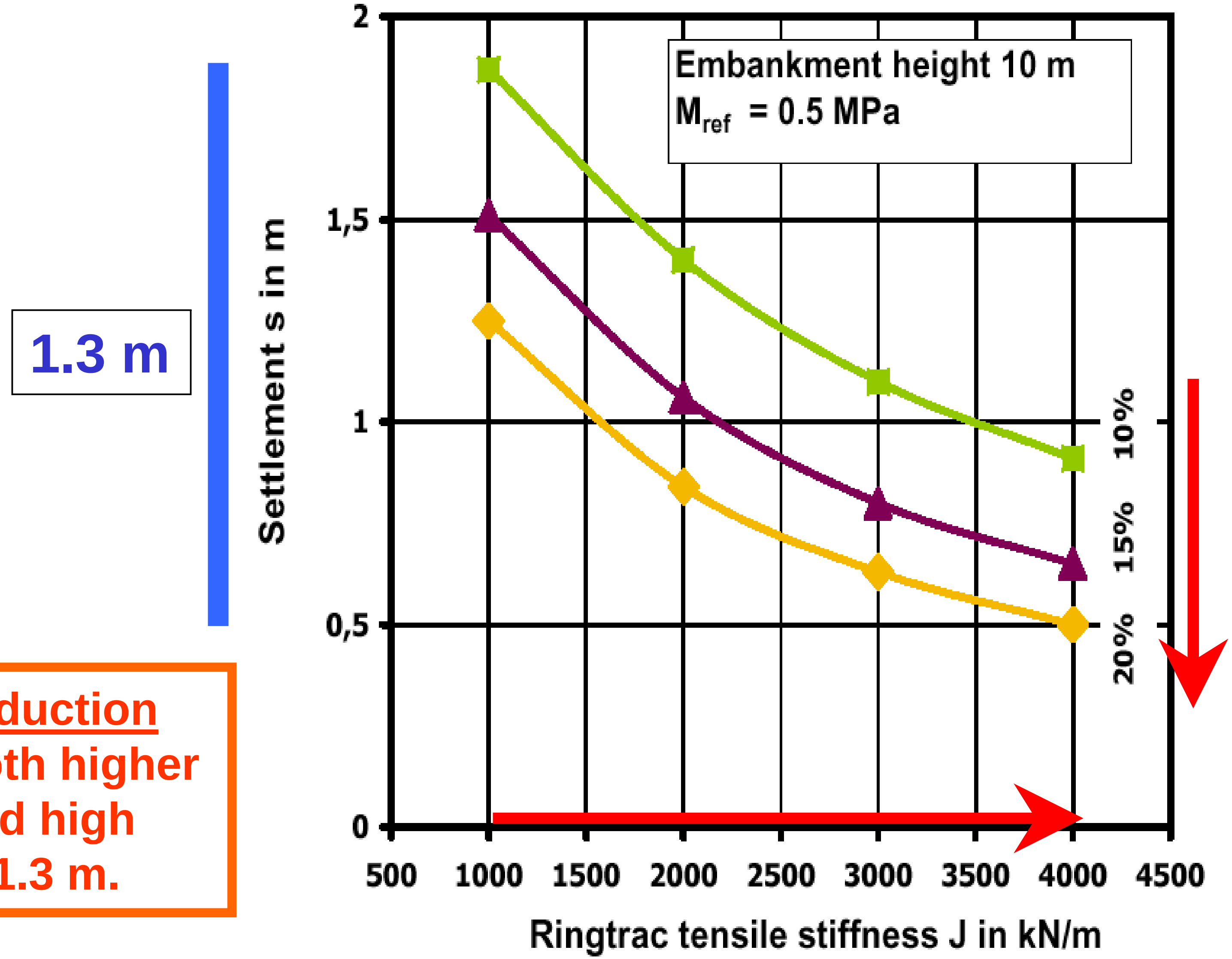
0.4 m



Settlement reduction

ca. 0.5 m for 20% vs. 10% columns

I. e. a higher modulus J provides a double effect ! (1 m)



Settlement reduction combining both higher modulus J and high "%" is about 1.3 m.

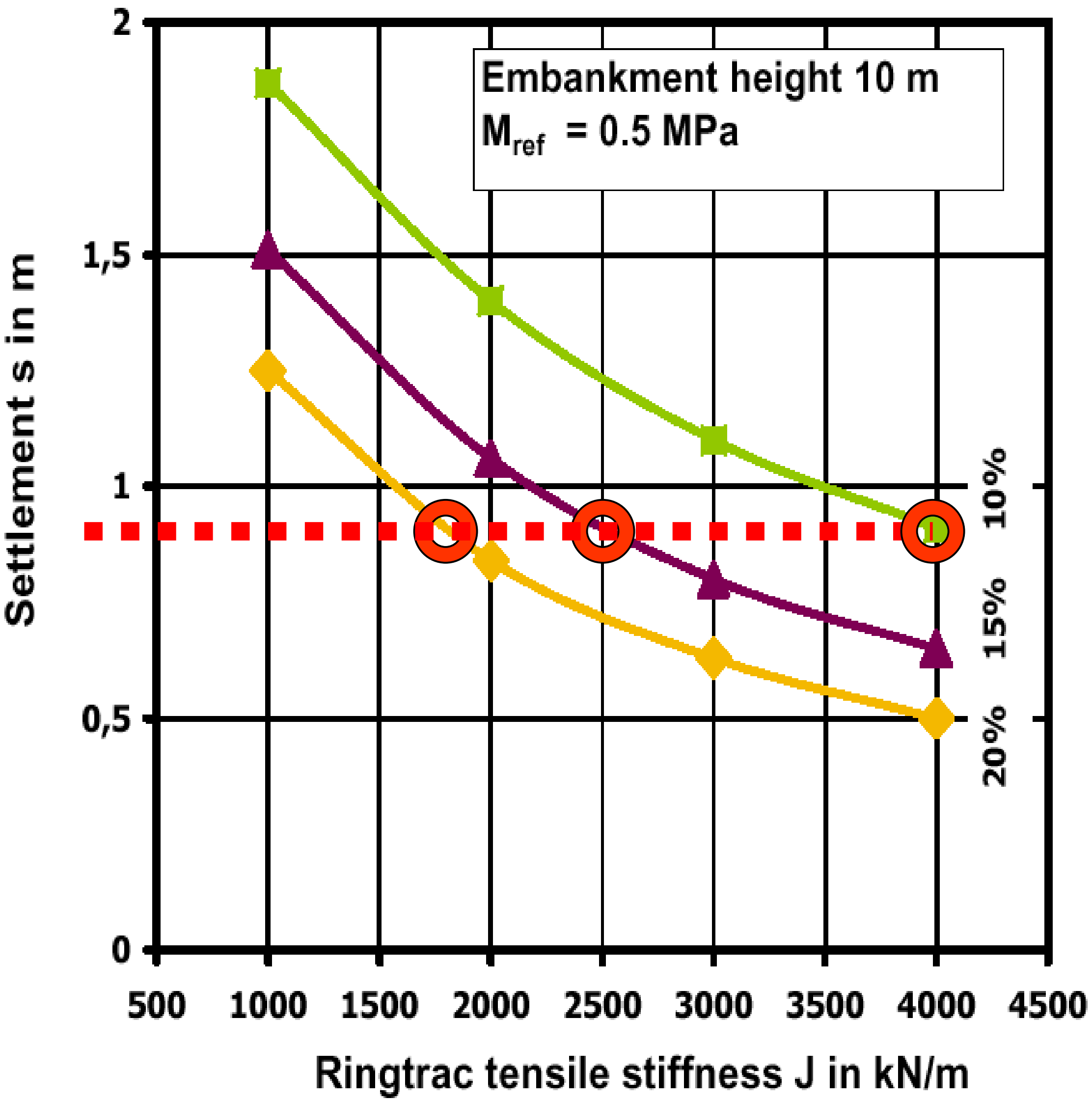
J = 4000 kN/m 10%

J = 2500 kN/m 15%

J = 2000 kN/m 20%

It is more efficient to use a lower percentage of GEC with a higher modulus…..

- **material**
- **equipment**
- **energy**
- **time**
- **manpower**



1. **Bearing,** **pile-similar elements;**
   even in extremely soft soils….at the same time drainage elements, although it is not the main function.
2. **Permeable:** **accelerated settlement during construction, at the same time min influence on the natural hydraulic environment.**
3. **Ductile, “self-regulating” system**
   embankment - horizontal Fortrac^{R}-geogrid reinforcement - Ringtrac - soft subsoil.
4. **“Hybrid” system**

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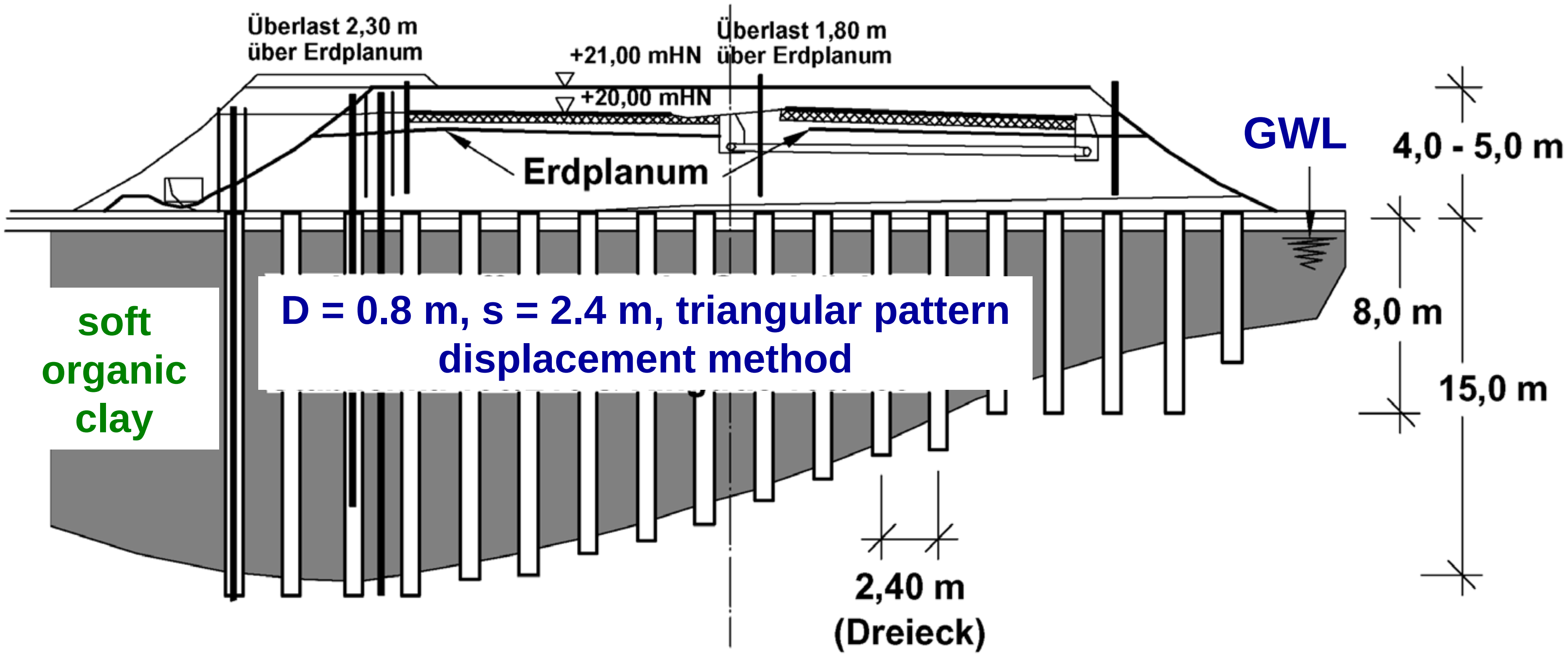
Autobahn A 20, Tessenitz, Germany, 1998,
GEC Ringtrac^{R} 100 & 200

km 92+550 – 92+950



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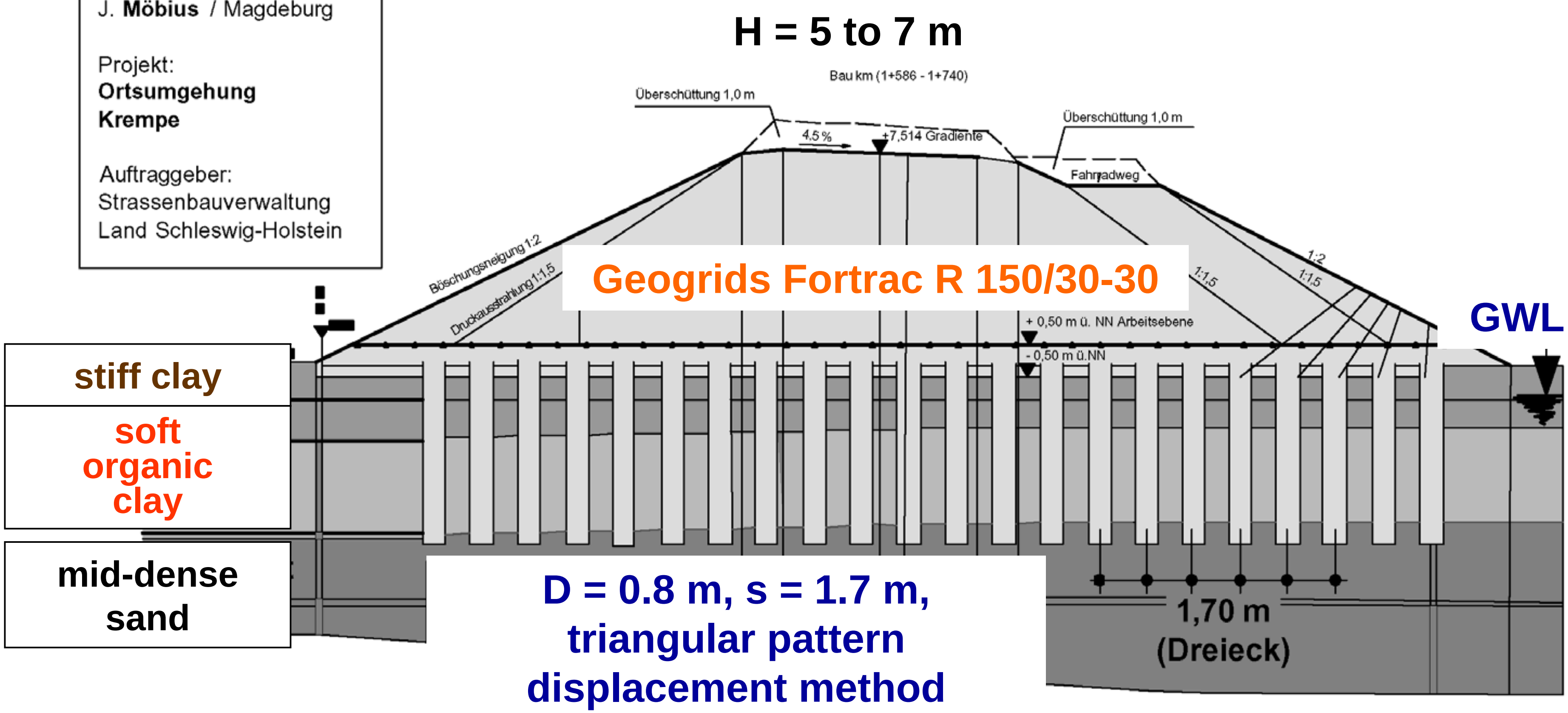
National road bypass Krempe, Germany, 1999,
GEC Ringtrac^R 100 & 200

Quelle:
J. **Möbius** / Magdeburg

Projekt:
Ortsumgehung Krempe

Auftraggeber:
Strassenbauverwaltung
Land Schleswig-Holstein

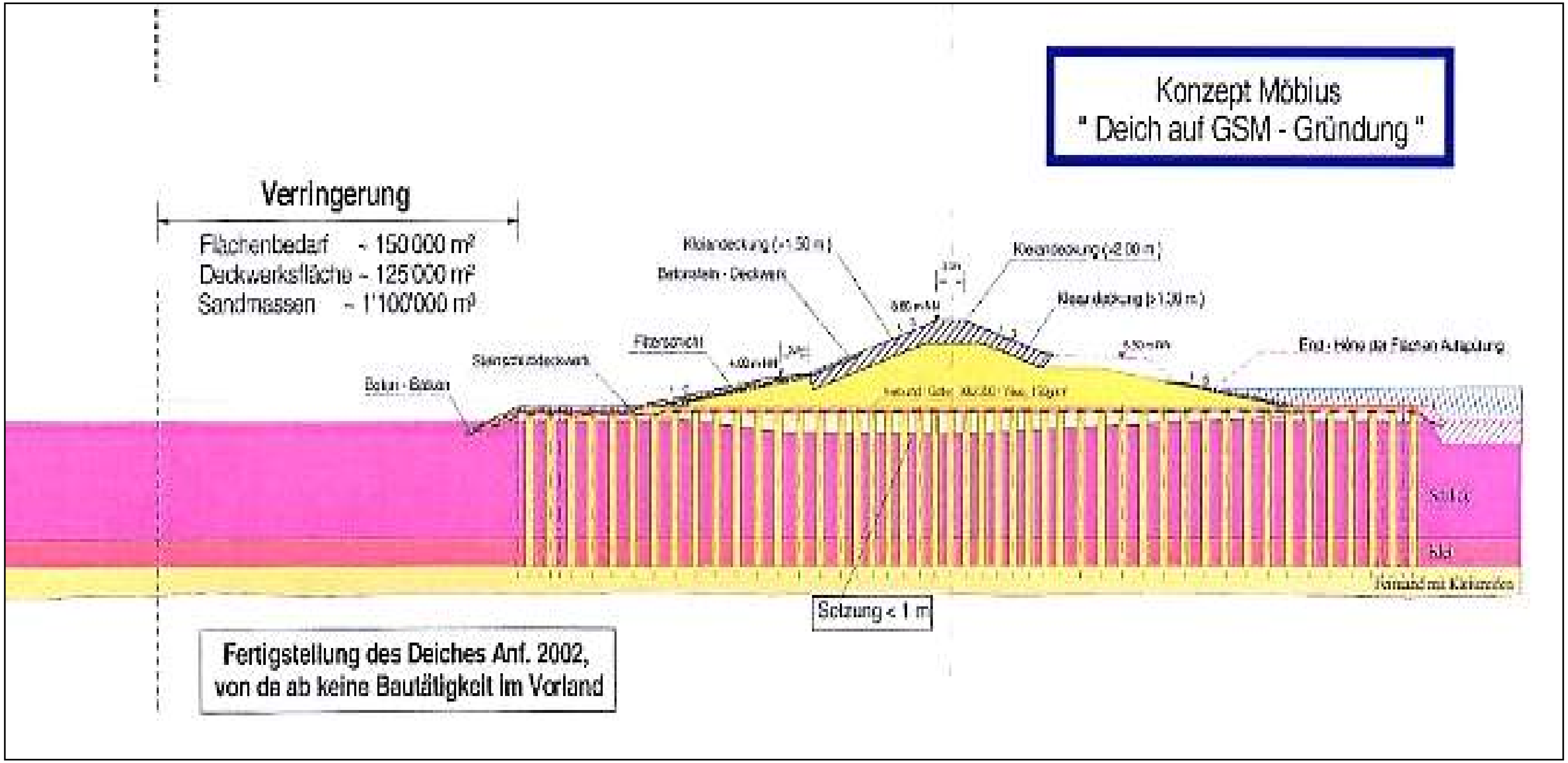


EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R] , Germany, 2001+

over 60.000 columns with a total length of about 700 km

HUESKER

EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R], Germany, 2001+



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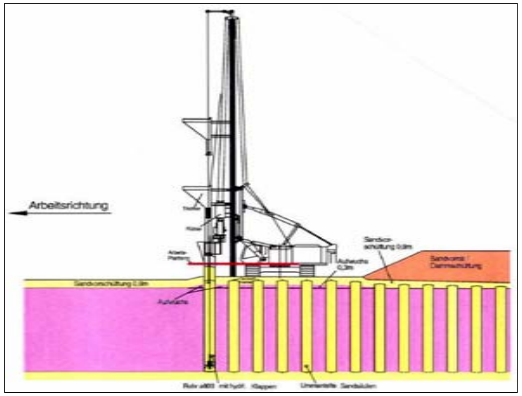
EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R] , Germany, 2001+



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EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R] , Germany, 2001+

EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac^R^, Germany, 2001+

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EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R] , Germany, 2001+

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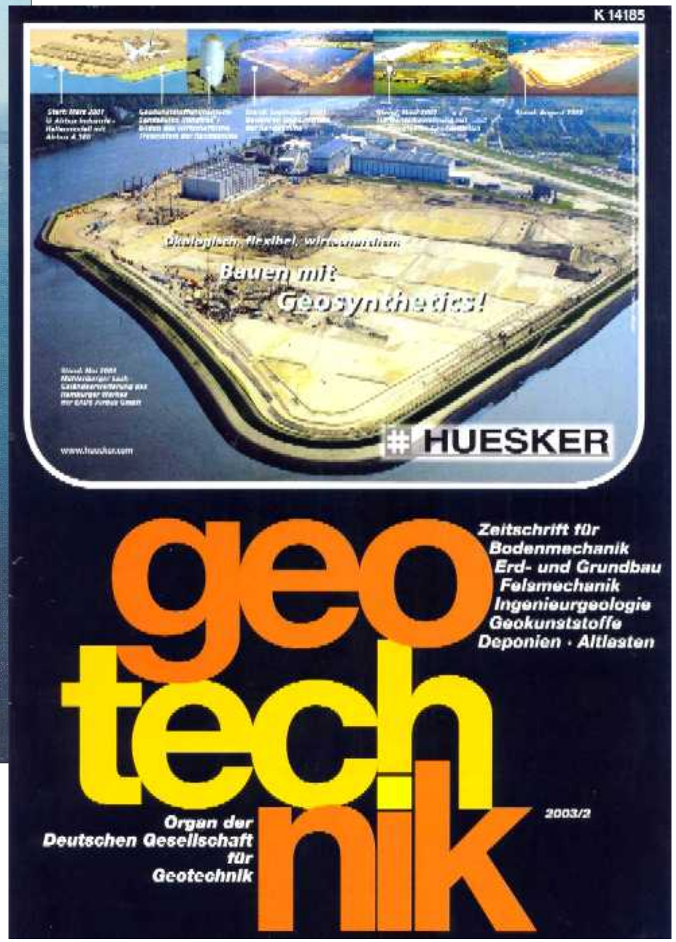
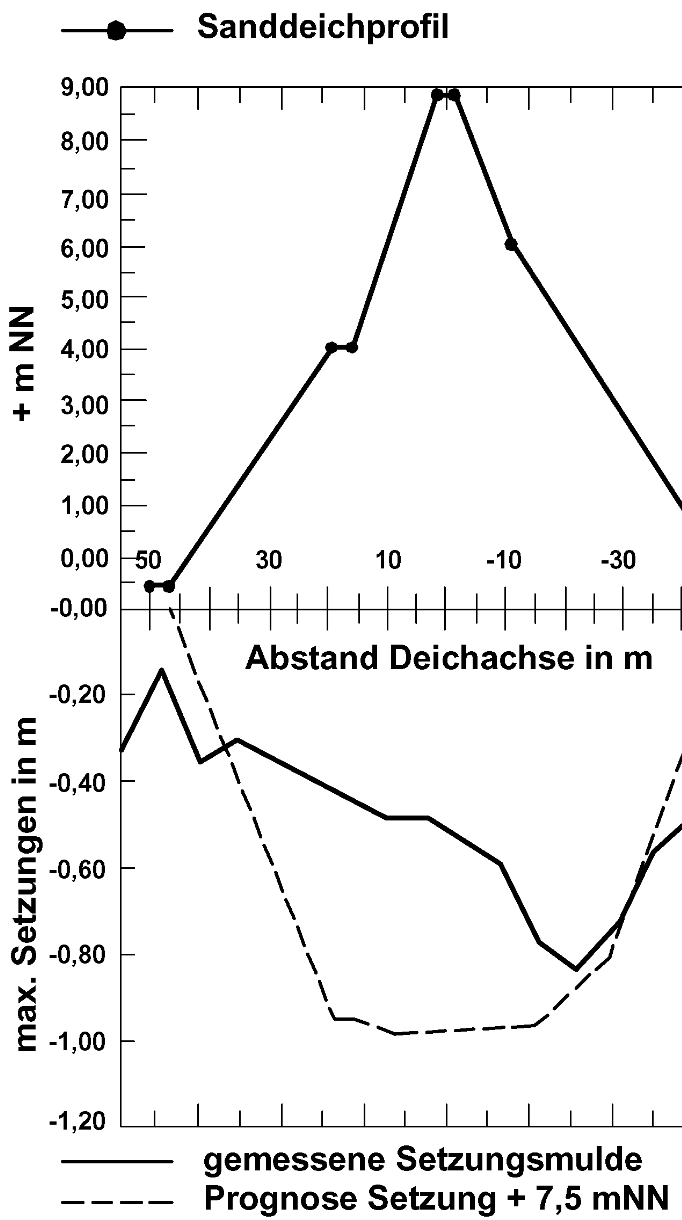
EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R] , Germany, 2001+



EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R] , Germany, 2001+



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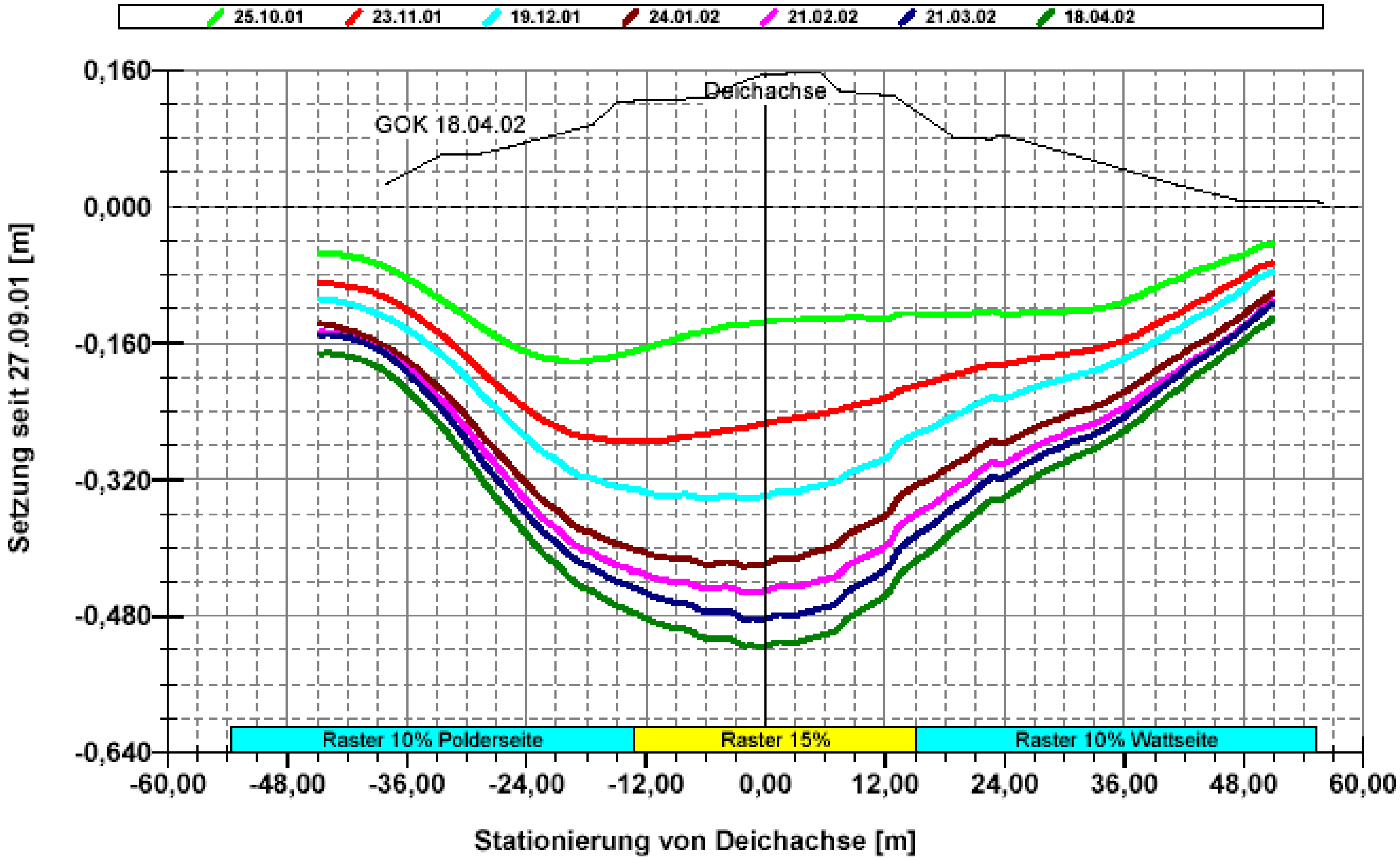
EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R] , Germany, 2001+



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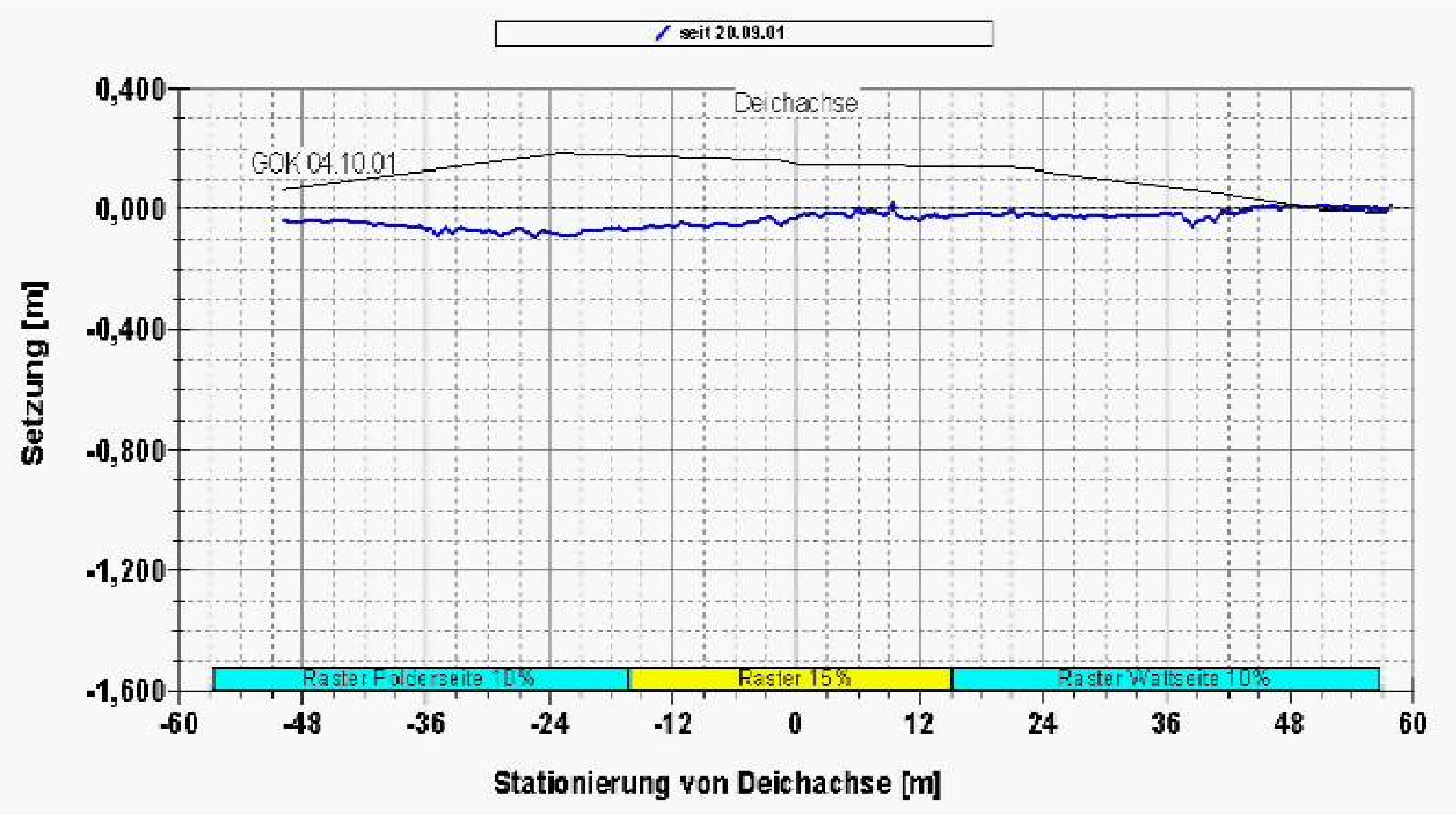
EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R] , Germany, 2001+



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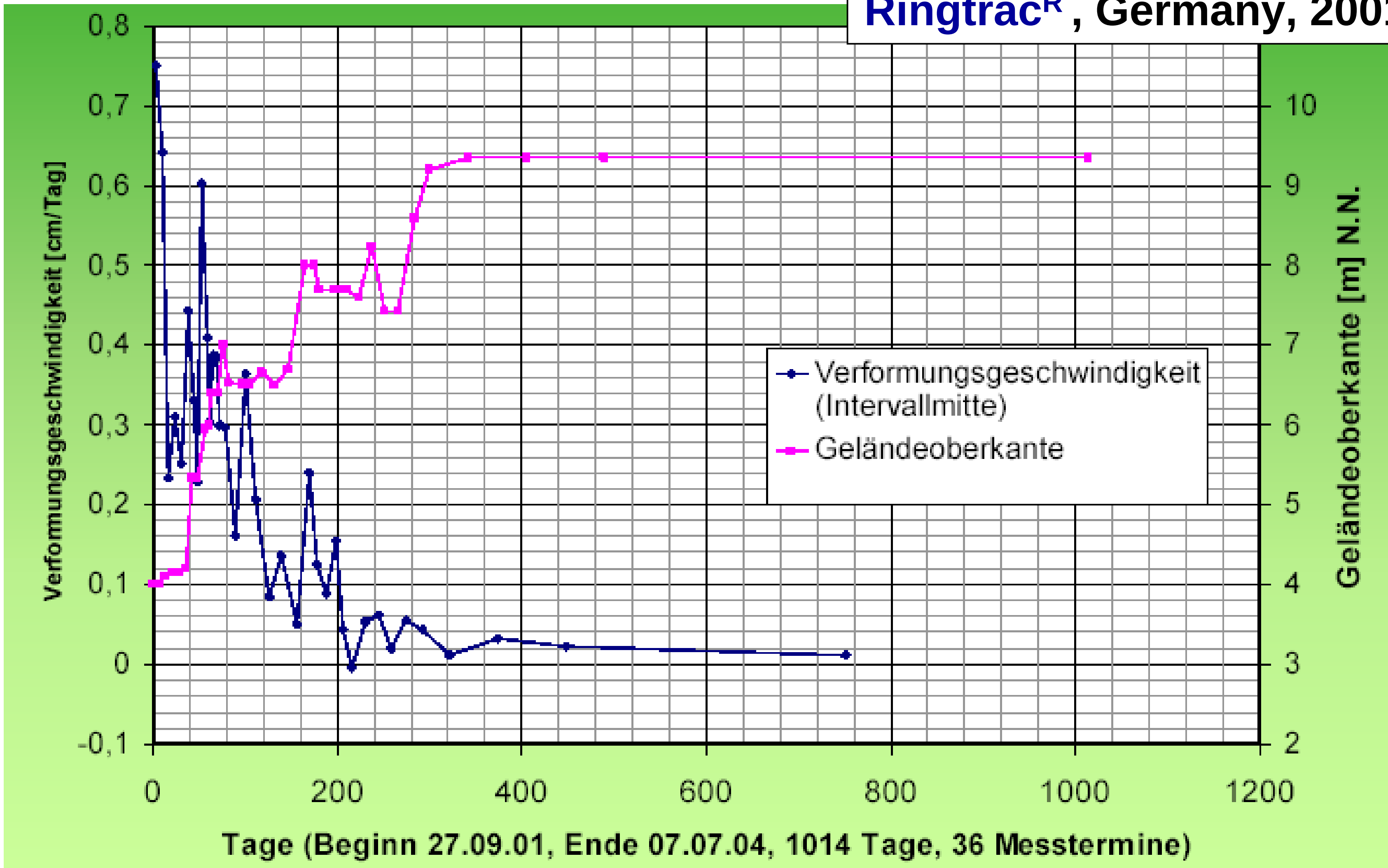
EADS (Airbus) land reclamation in Hamburg, GEC Ringtrac[R] , Germany, 2001+



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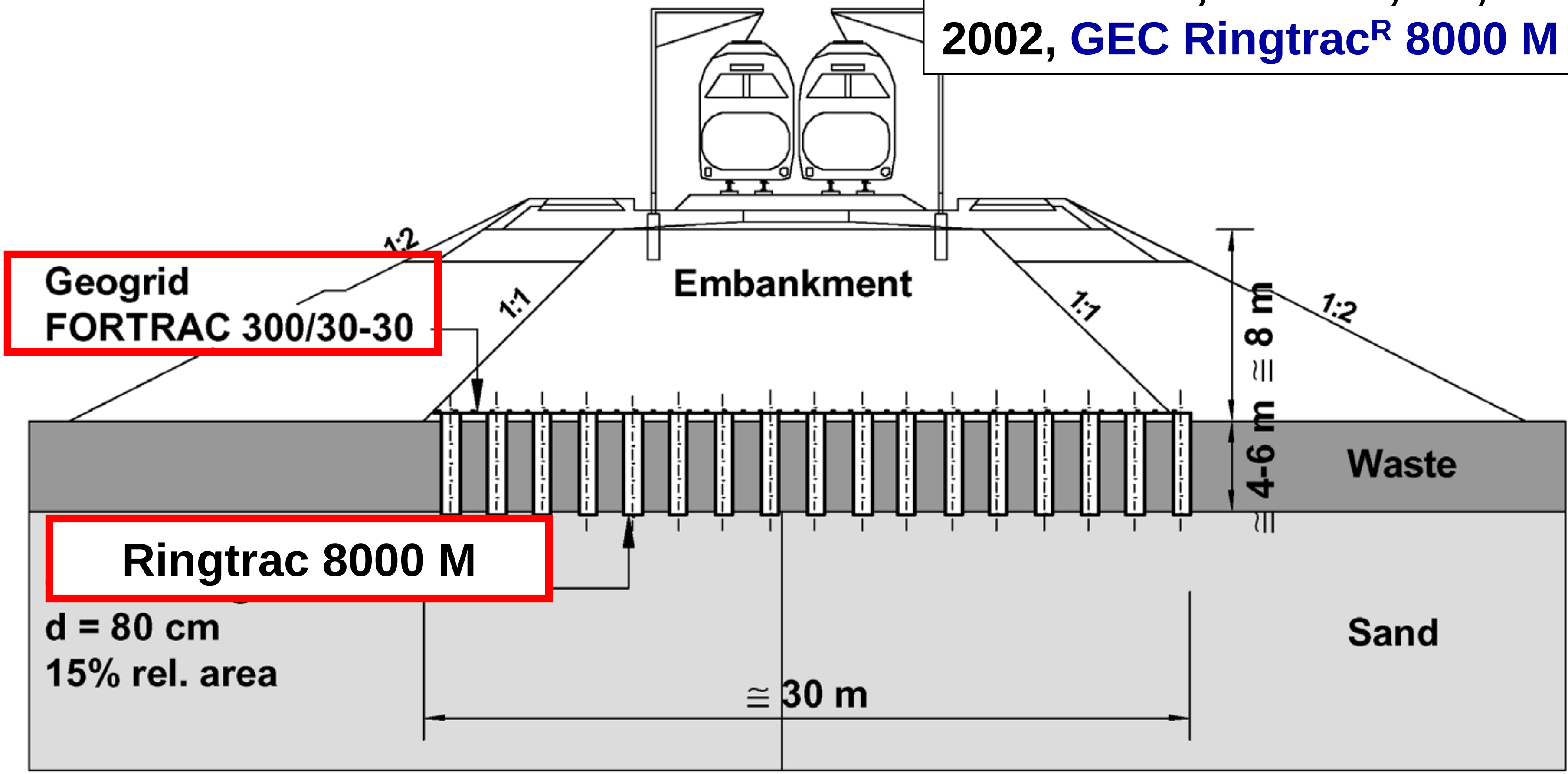
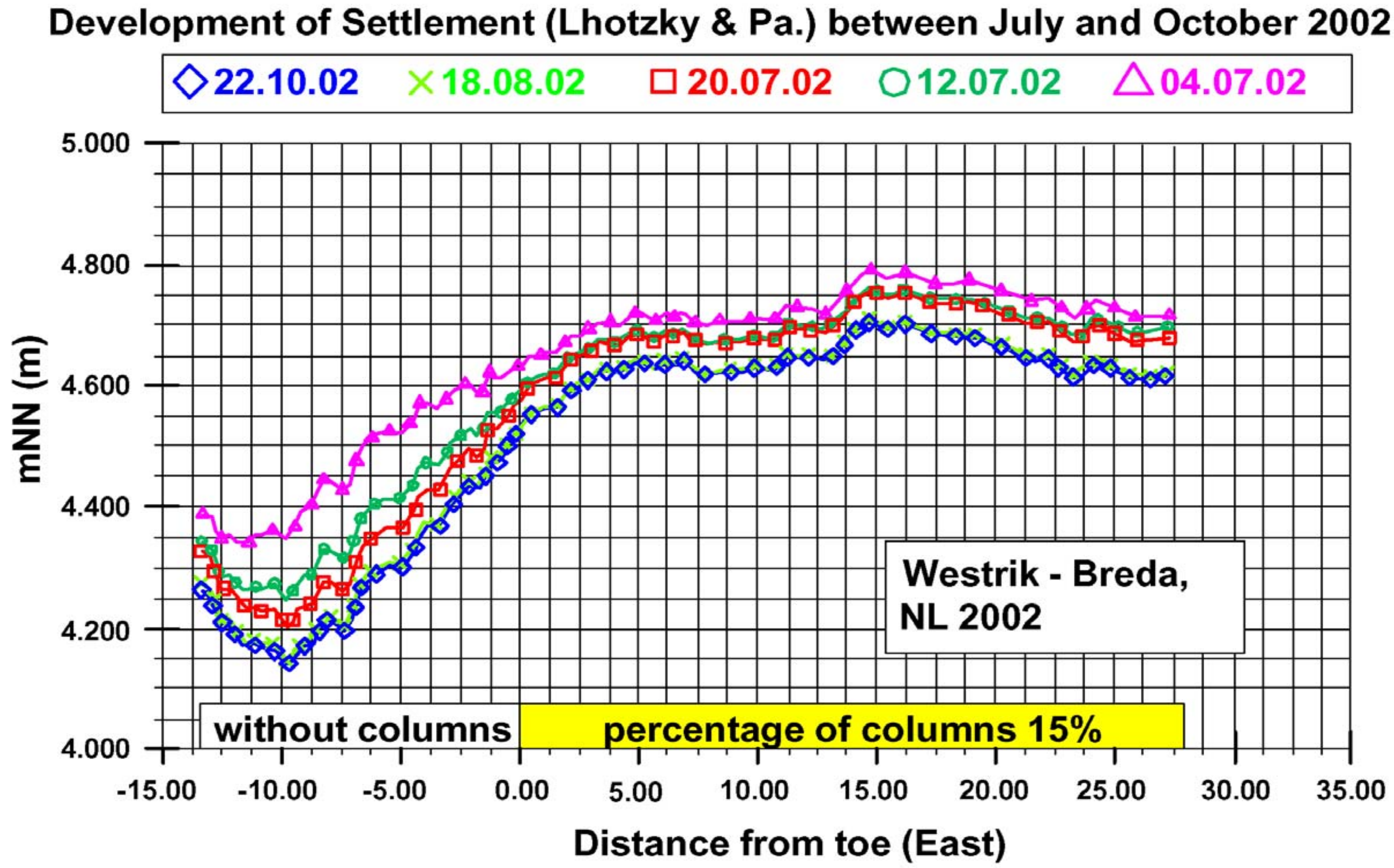
High-speed rail link Paris-Amsterdam, Westrik, NL, 2002, GEC Ringtrac^{R} 8000 M



High-Speed-Link Paris - Amsterdam
Westrik - Breda, NL 2002

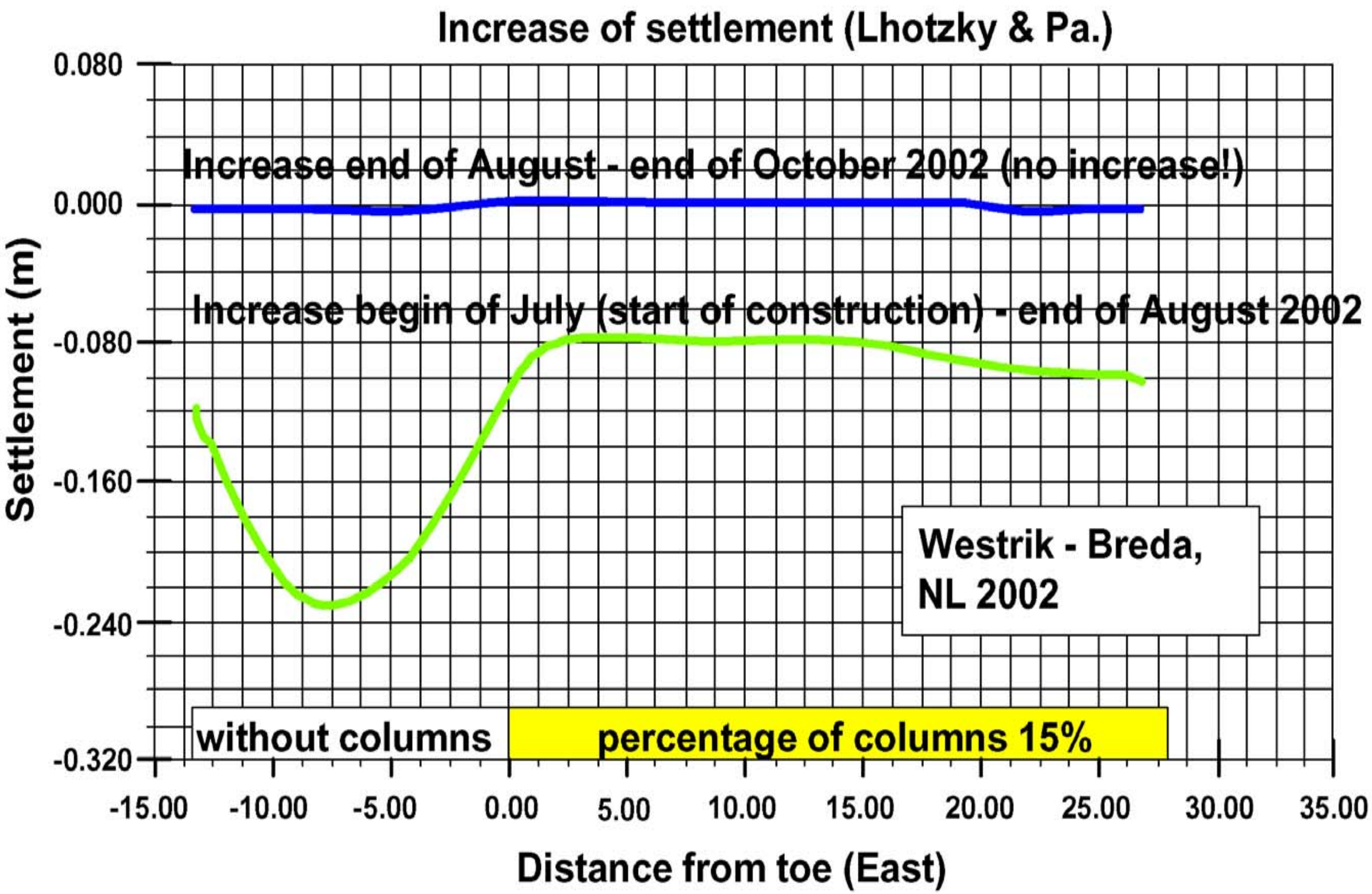
HUESKER

High-speed rail link Paris-Amsterdam, Westrik, NL, 2002, GEC Ringtrac^{R} 8000 M



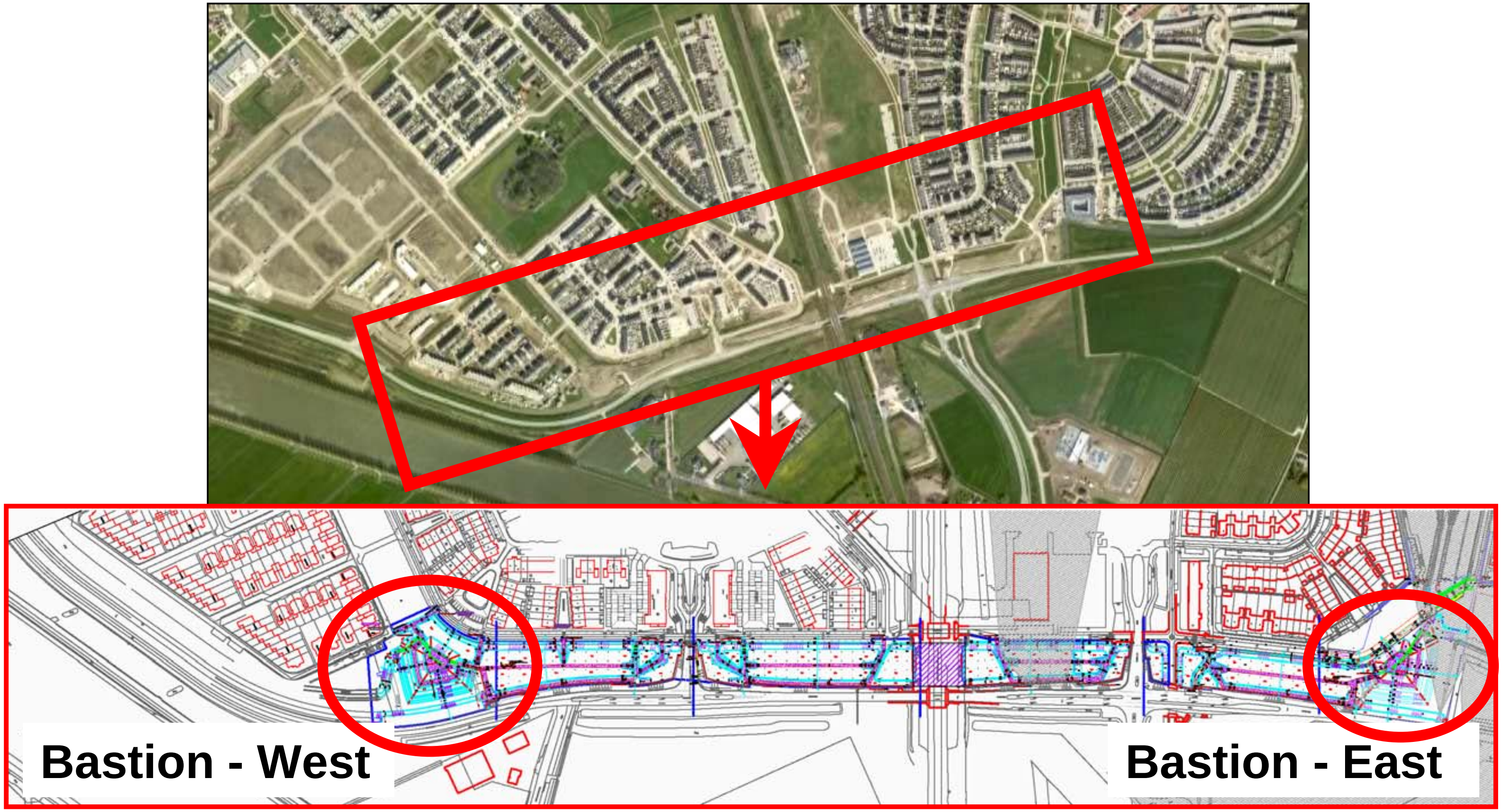
HUESKER

High-speed rail link Paris-Amsterdam, Westrik, NL, 2002, GEC Ringtrac^{R} 8000 M



„Bastions“ at Houten, NL, 2005, Ringtrac[R] 2000 & 3500 M

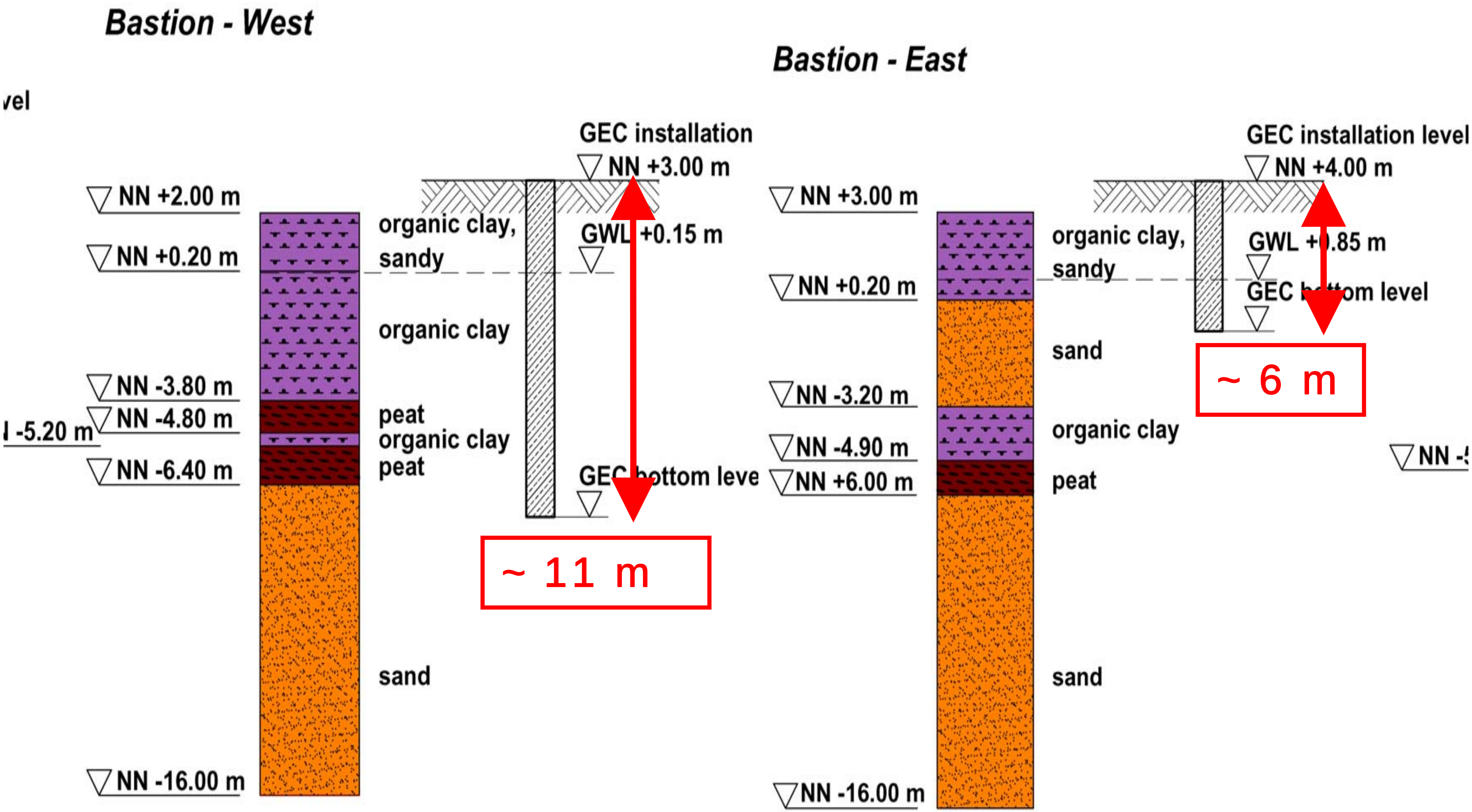
About 6 m high embankments on soft soils, high GWL, with a sophisticated geometry, max 0.4 m settlement allowed



HUESKER

Typical geotechnical situation and GEC

„Bastions“ at Houten, NL, 2005, Ringtrac[R] 2000 & 3500 M



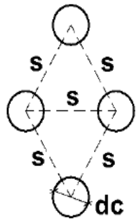
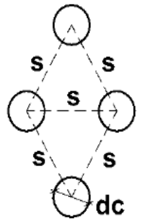
Typical geotechnical situation and GEC

„Bastions“ at Houten, NL, 2005, Ringtrac^R 2000 & 3500 M

Soft Soil Layer:	organic clay & peat
thickness	7.5 m
West	
properties	γ = 14 kN/m³ / φ‘ = 17° / c´= 2.5 kN/m² $E_{s.pref}$ = 2000 kN/m² ($p_{.ref}$ = 100 kN/m²)
ground water level	- 2.0 m
Soft Soil Layer:	sandy organic clay
thickness	3.0 m
East	
properties	γ = 17 kN/m³ / φ‘ = 22,5° / c´= 2 kN/m² $E_{s.ref}$ = 3000 kN/m² ($p_{.ref}$ = 100 kN/m²)
ground water level	n.a.

Typical geotechnical situation and GEC

„Bastions“ at Houten, NL, 2005, Ringtrac[R] 2000 & 3500 M

Foundation System:	geosynthetic encased columns	geosynthetic encased columns
geometry	 s = 2.00 m dc = 0.80 m **West**	 s = 2.30 m dc = 0.80 m **East**
column fill	γ = 19 kN/m³ / φ‘ = 32.5° / c = 0 kN/m² (sand)	γ = 19 kN/m³ / φ‘ = 32.5° / c = 0 kN/m² (sand)
encasement	Ringtrac® 3500 PM UTS = 200 kN/m J_K = 3500 kN/m J_d = 2100 kN/m	Ringtrac® 2000 PM UTS = 130 kN/m J_K = 2000 kN/m J_d = 1000 kN/m
basal reinforcement	Stabilenka® 500/100 UTS = 500 kN/m	Stabilenka® 500/100 UTS = 500 kN/m
allowed settlements	≤ 0.40 m	≤ 0.15 m

* J_K = short term radial tensile stiffness; J_d = long term radial tensile stiffness (120 years)

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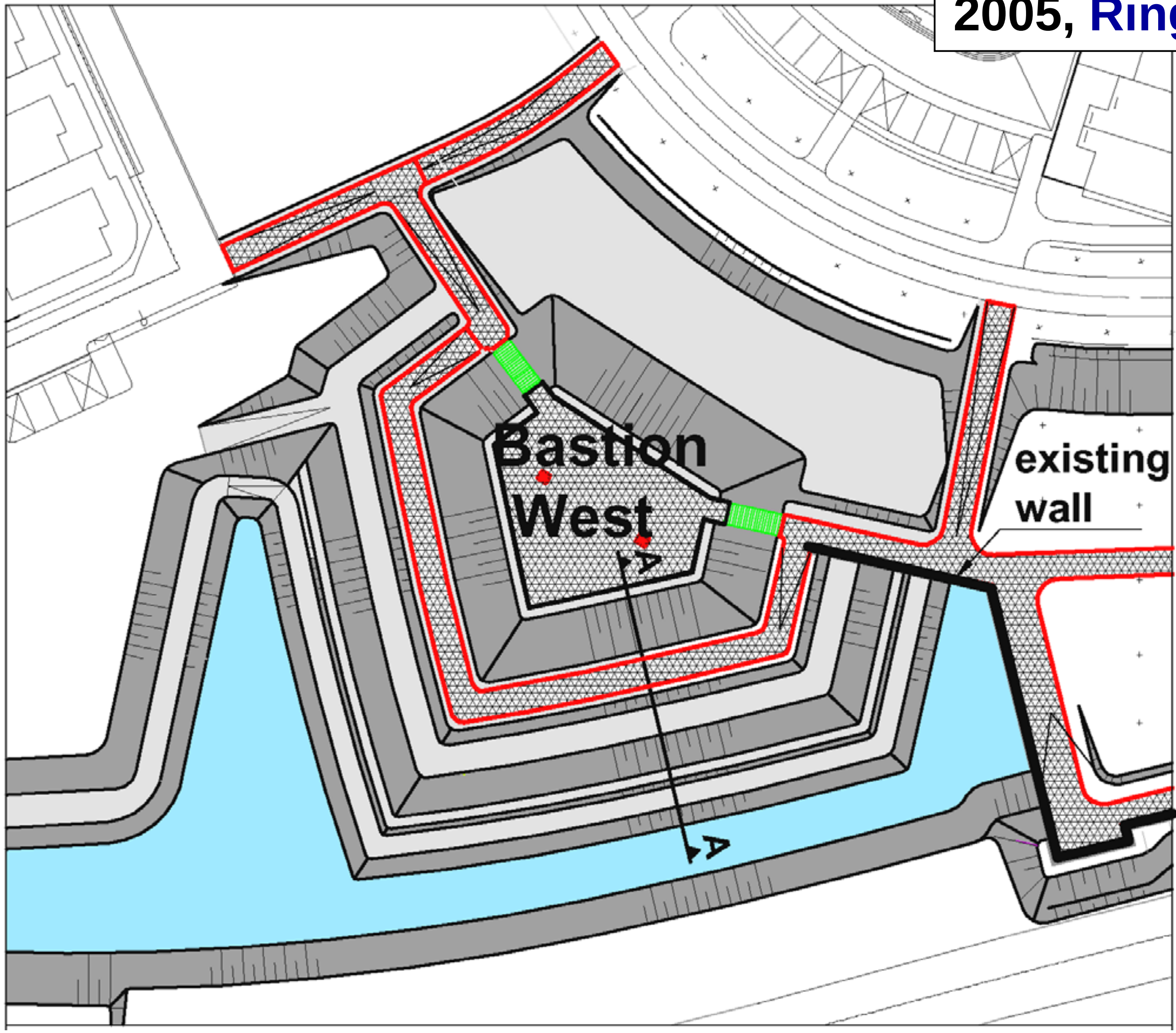
Typical plan-view

„Bastions“ at Houten, NL, 2005, Ringtrac[R] 2000 & 3500 M



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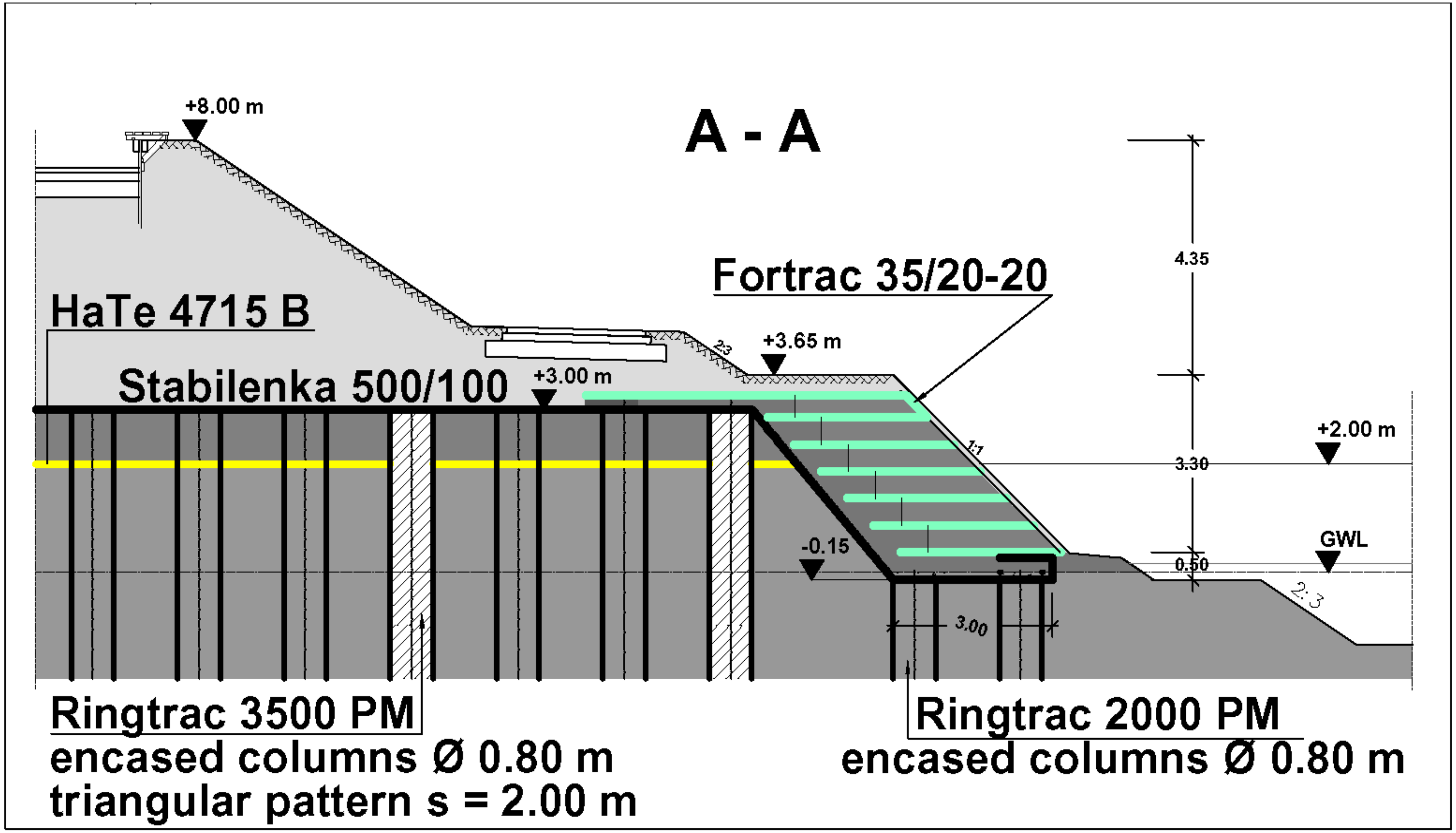
Typical cross-section

„Bastions“ at Houten, NL, 2005, Ringtrac[R] 2000 & 3500 M



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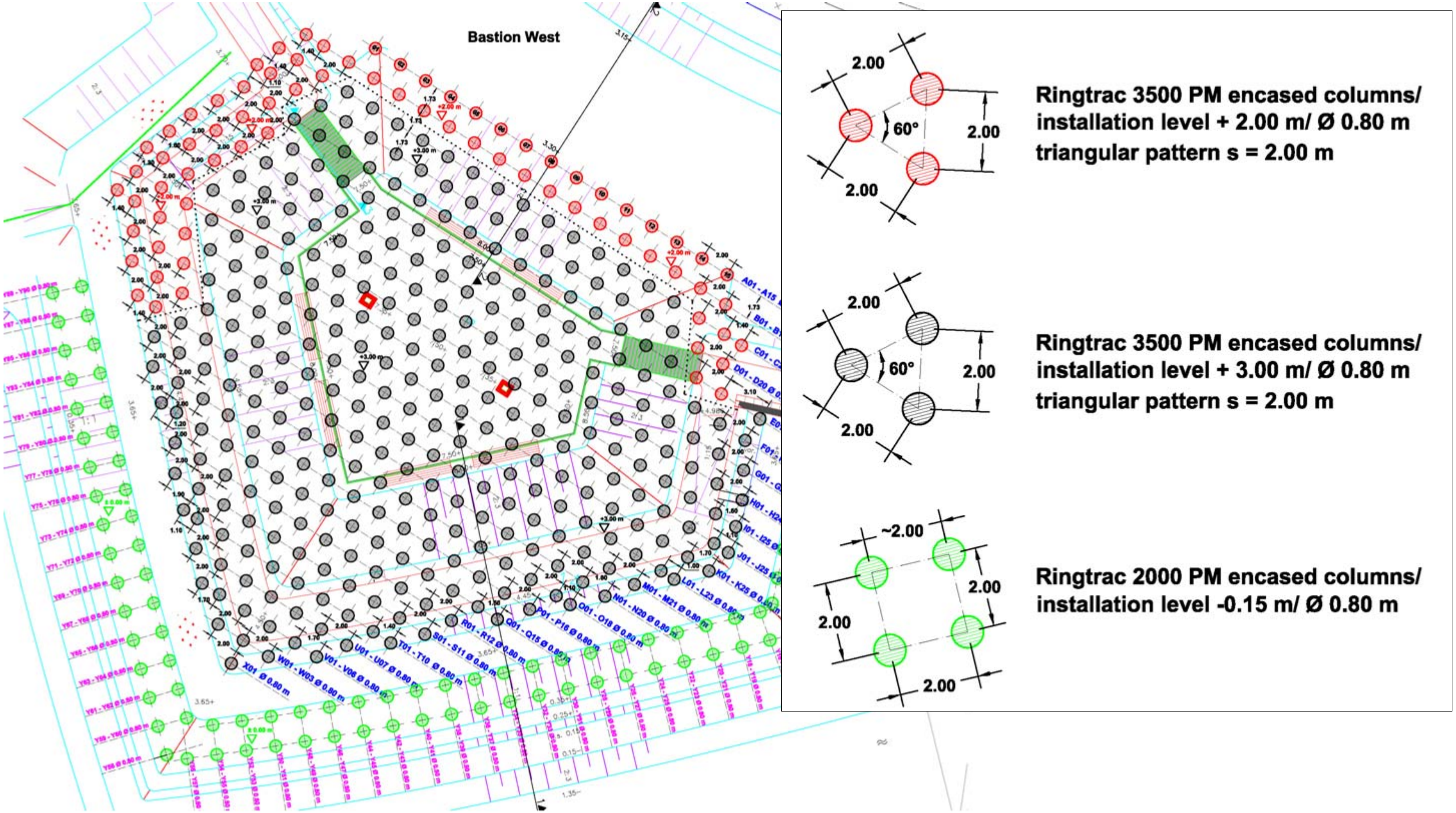
Typical installation pattern of GEC

„Bastions“ at Houten, NL, 2005, Ringtrac[R] 2000 & 3500 M



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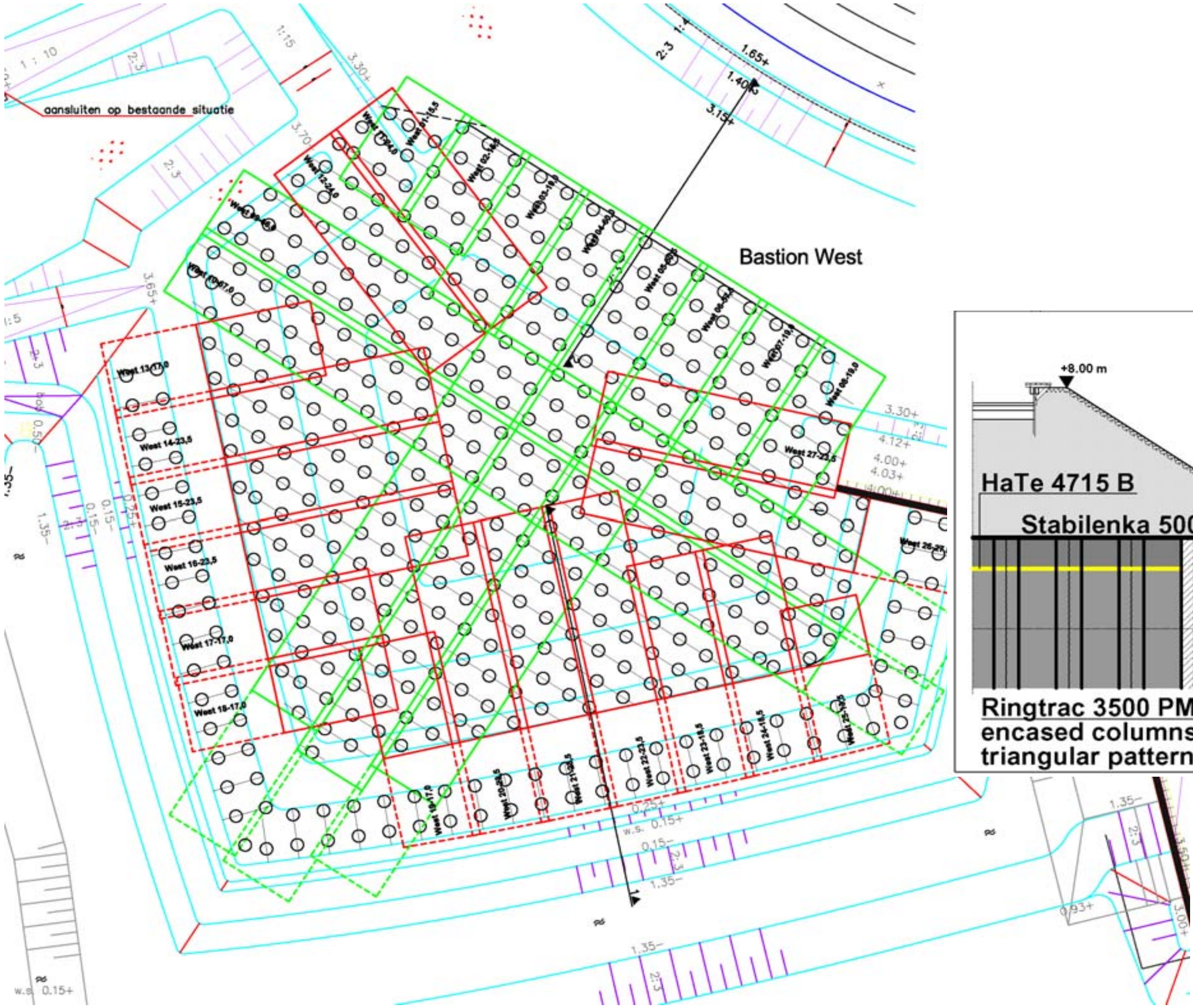
„Bastions“ at Houten, NL, 2005, Ringtrac^{R} 2000 & 3500 M

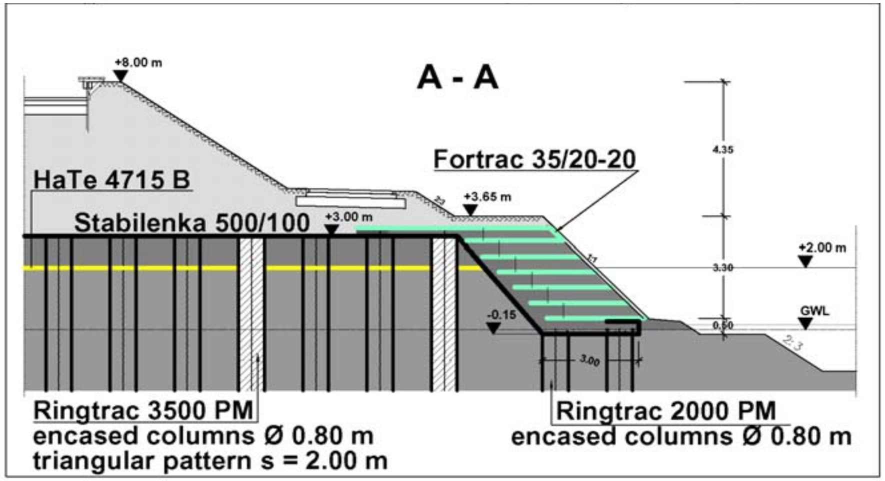
„Bastions“ at Houten, NL, 2005, Ringtrac^{R} 2000 & 3500 M

HUESKER

Horizontal reinforcement on top of GEC

„Bastions“ at Houten, NL, 2005, Ringtrac[R] 2000 & 3500 M

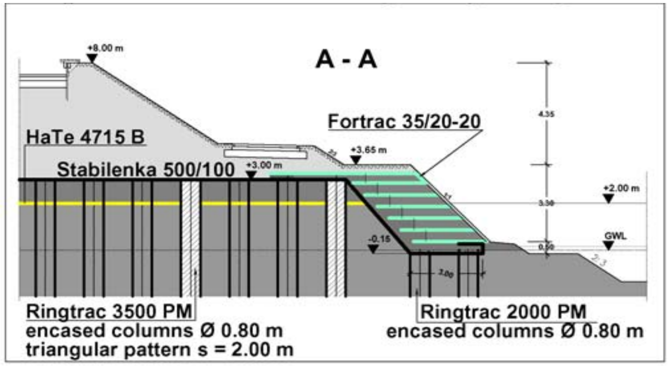




HUESKER

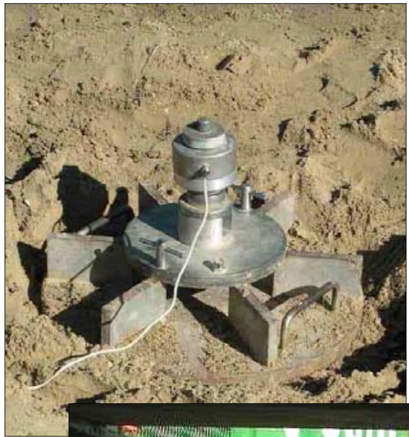
Horizontal reinforcement on top of GEC

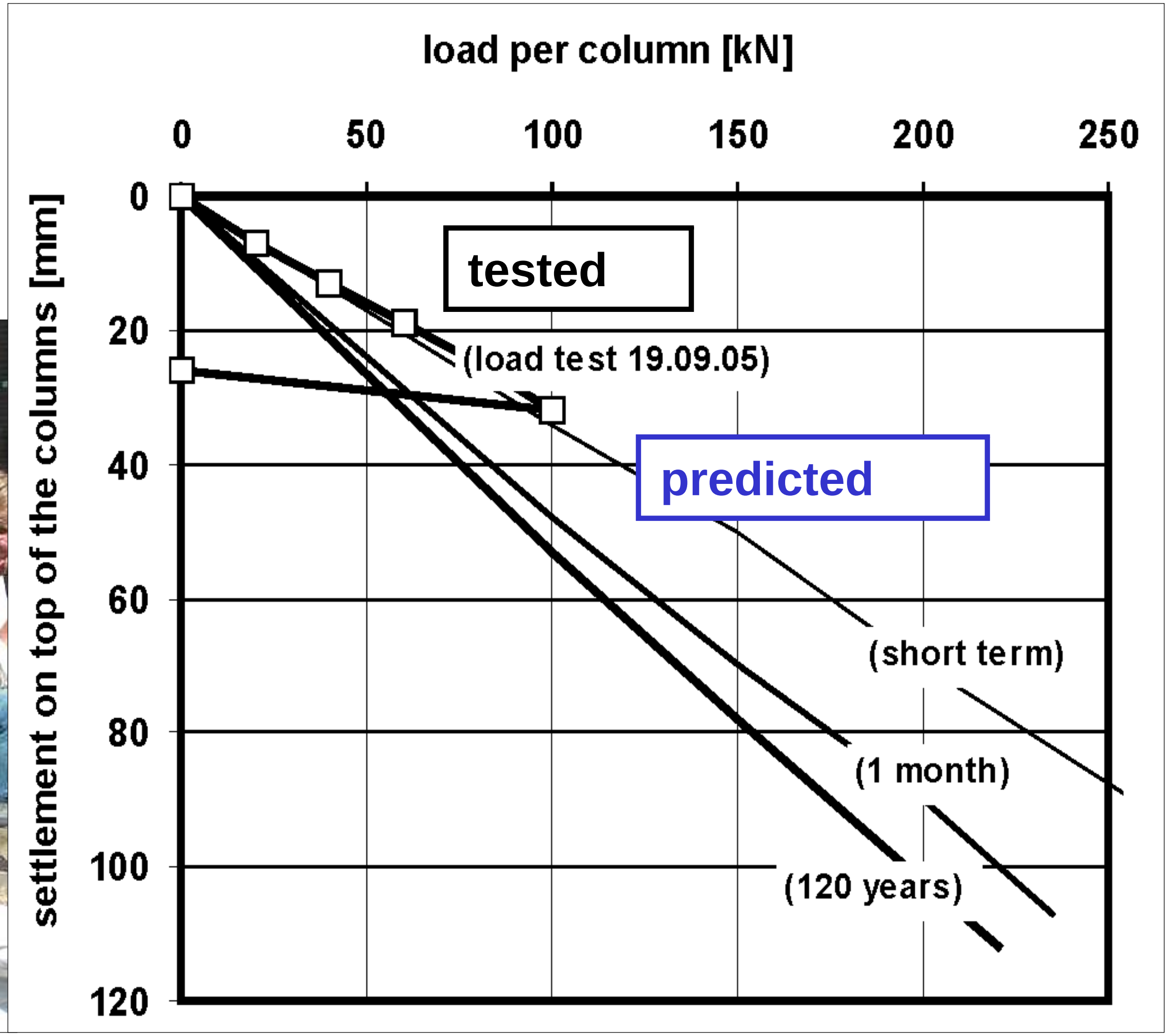
„Bastions“ at Houten, NL, 2005, Ringtrac^R 2000 & 3500 M



Loading plate tests on GEC

„Bastions“ at Houten, NL, 2005, Ringtrac[R] 2000 & 3500 M





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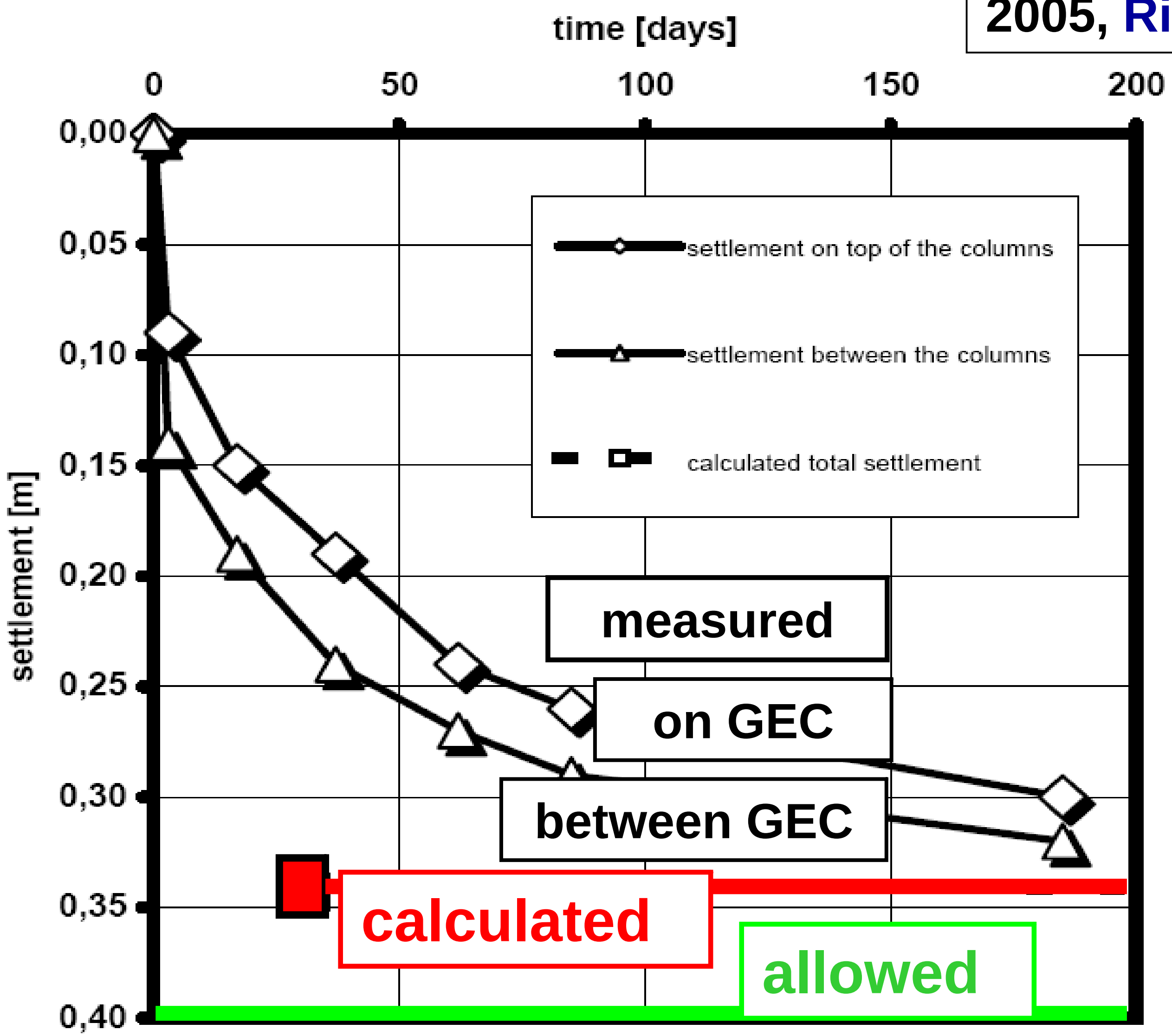
Long-term settlements West

„Bastions“ at Houten, NL,
2005, Ringtrac[R] 2000 & 3500 M



„Bastions“ at Houten, NL, 2005, Ringtrac[R] 2000 & 3500 M

Bridging Sinkholes

Bridging sinkholes

Bridging sinkholes

Bridging sinkholes

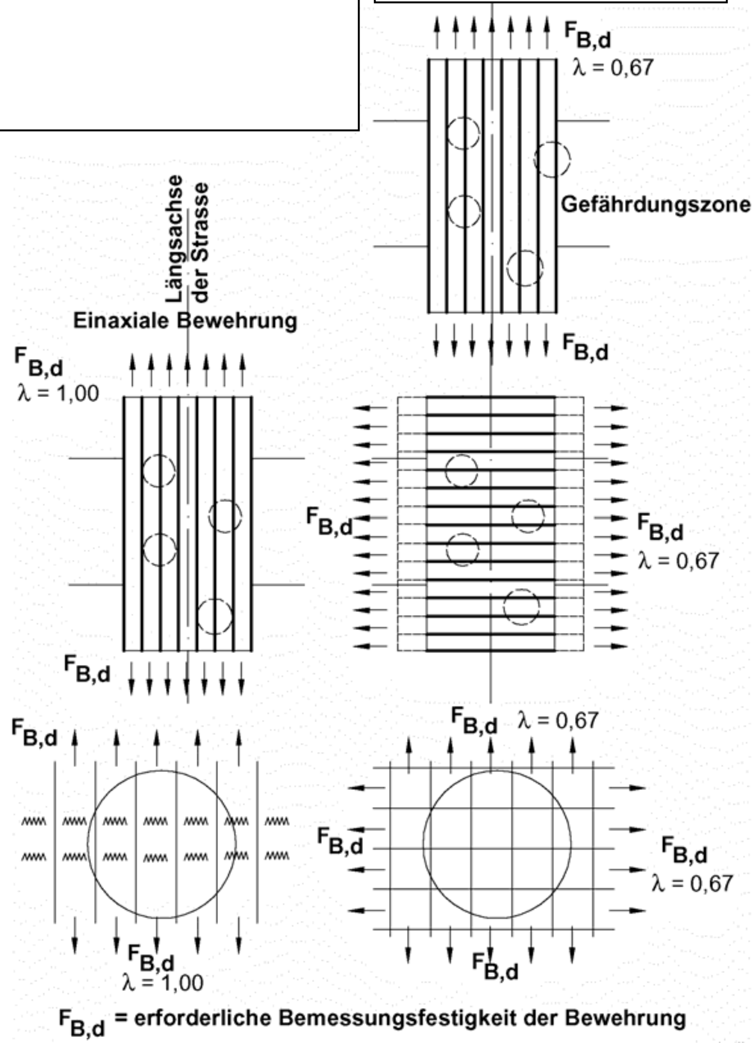
Bridging sinkholes

Overbridging:

-**uniaxial system:** uniaxial product
installed in the longitudinal direction

-**biaxial system:**
orthogonally installed
two uniaxial products or one layer of biaxial product (but the overlaps
should be dimensioned!!!)

Uniaxial	biaxial



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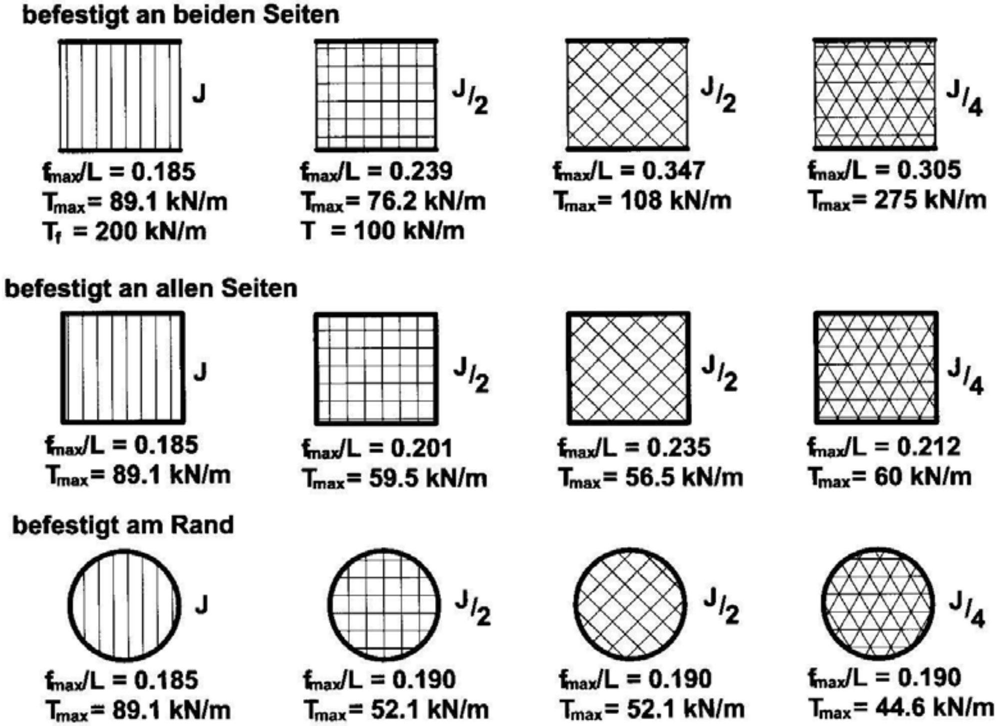
Bridging sinkholes

fixed at both edges

fixed at all edges

fixed around



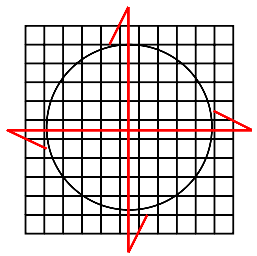
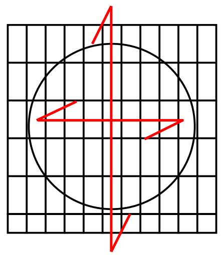
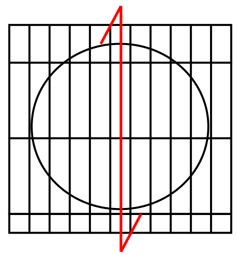
$$\varepsilon_{max} = \frac{8}{3} \cdot \left(\frac{f_{max}}{D}\right)^2$$

OVERBRIDGING SYSTEMS
(GOURC & VILLARD; 2000)

diameter or size: D = 2,0 m,
vertical loead on reinforcement level: q = 55 kN/m²,
stiffness modulus J = 909 kN/m
f_{max} – max. deflection
T_{max}- max. tension force by f_{max}/D)

Bridging sinkholes

Design methods for different load transfer models

Load transfer models	biaxial	biaxial	uniaxial
Reinforcement	**isotropic**	**anisotropic**	**ultra anisotropic**
Principle presentation			
Design method	BS 8006 [2] Giroud et al. [3] B.G.E. [4] A.S.T. [5] Wang et al. [6]	B.G.E. [4]	Giroud et al. [3] R.A.F.A.E.L. [7] Wang et al. [6] BS 8006 [2]

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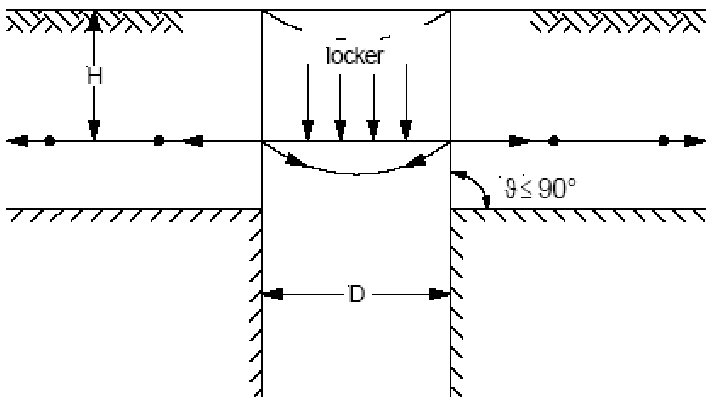
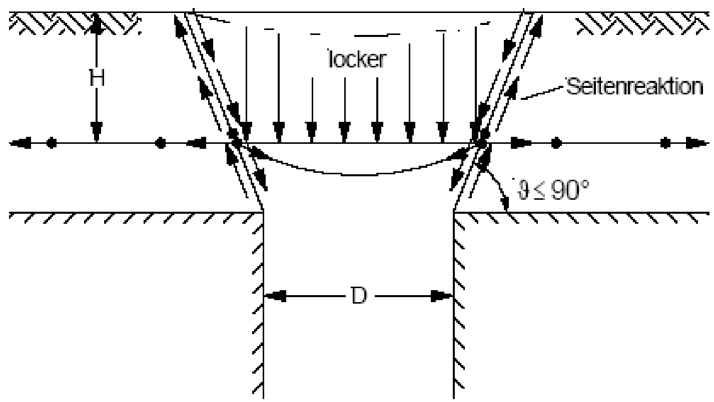
Bridging sinkholes

General modes of failure

<table>
<tr><th colspan="2">Einbruch-Modell</th></tr>
<tr><th>ohne Seitenreaktion</th><th>mit Seitenreaktion</th></tr>
<tr><td>nichtbindiger Boden mit geringer Lagerungsdichte
vollständiger Bruch
volle Auflast auf Membran</td><td>nichtbindiger Boden mit geringer Lagerungsdichte
vollständiger Bruch
teilweise Lastabtrag über Seitenreaktion
reduzierte Auflast auf Membran</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Bild 1a</td><td>Bild 1b</td></tr>
</table>

Model without reaction of shear forces

Model with reaction of shear forces

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Bridging sinkholes

Arching models

Gewölbemodell	
zeitabhängig begrenzte Auflast	dauerhaft begrenzte Auflast
nichtbindiger Boden mit hoher Lagerungsdichte zeitlich begrenzter bis vollständiger Hochbruch zeitabhängig begrenzte Auflast auf Membran	hochkohäsiver (stabilisierter) Boden dauerhaft begrenzter Hochbruch dauerhaft begrenzte Auflast auf Membran
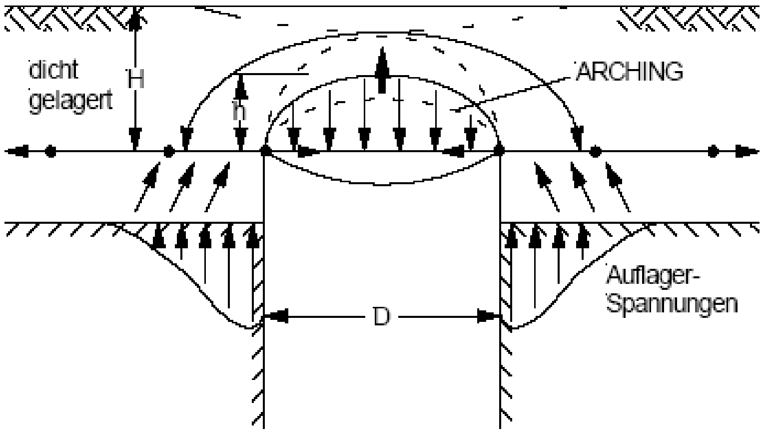	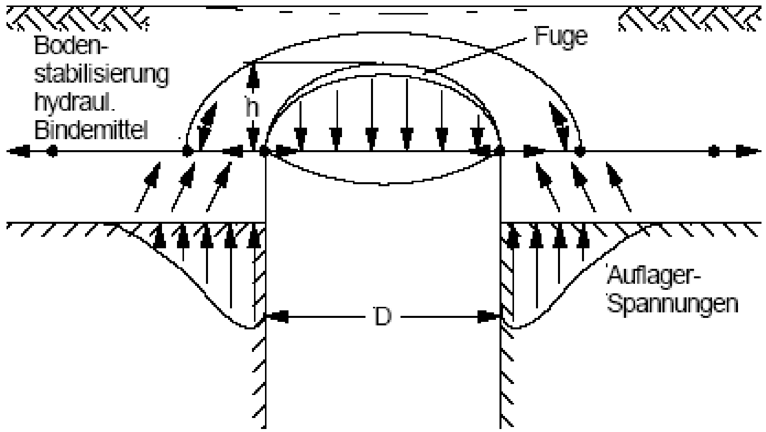
Bild 2a	Bild 2b

Short-term stable arch **Long-term stable arch**

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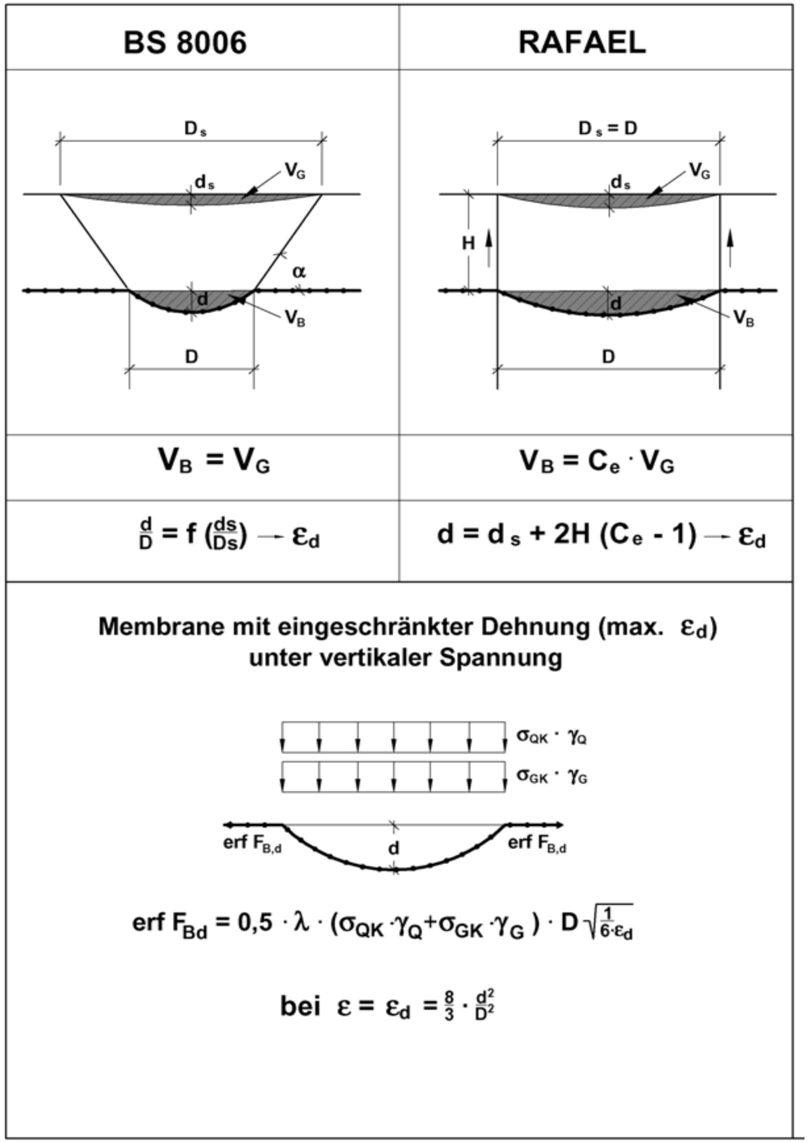
Bridging sinkholes

Design methods for shallow overbridging systems:

- a biaxial overbridging (BS 8006) but with the draw angle $\theta \geq 80°$ H/D $\leq 1{,}0$

-an uniaxial overbridging RAFAEL for
-H/D $\leq 3{,}0$

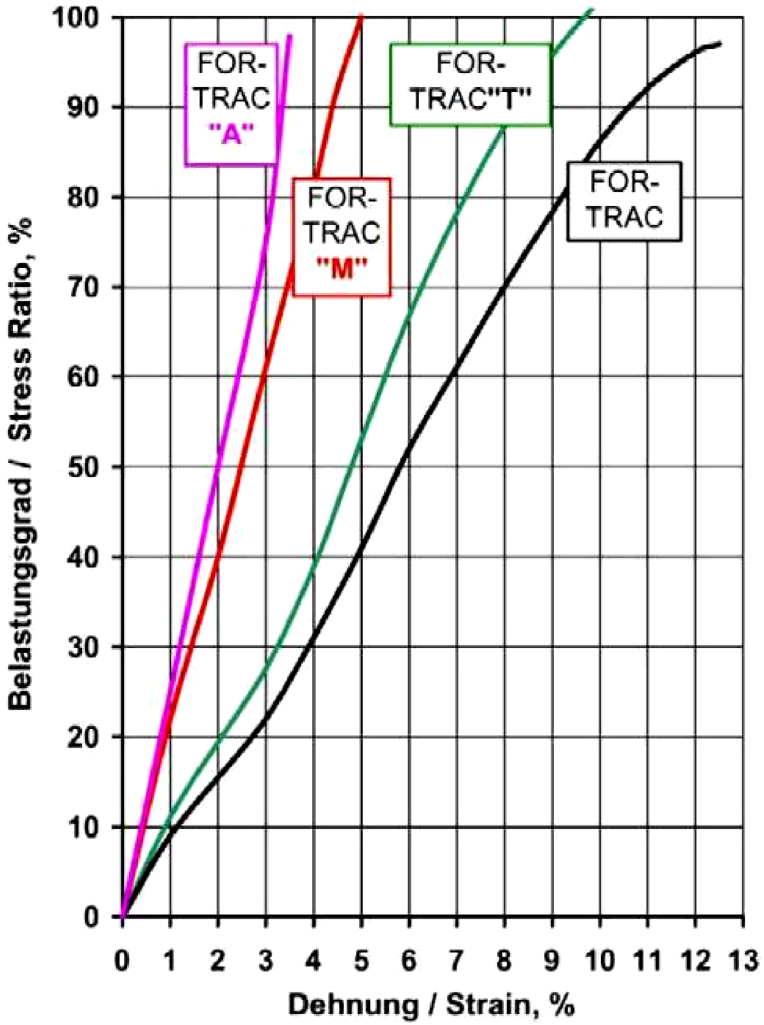


Estimation of allowable elongation due to allowable deflection of pavement (d_s/D_s)

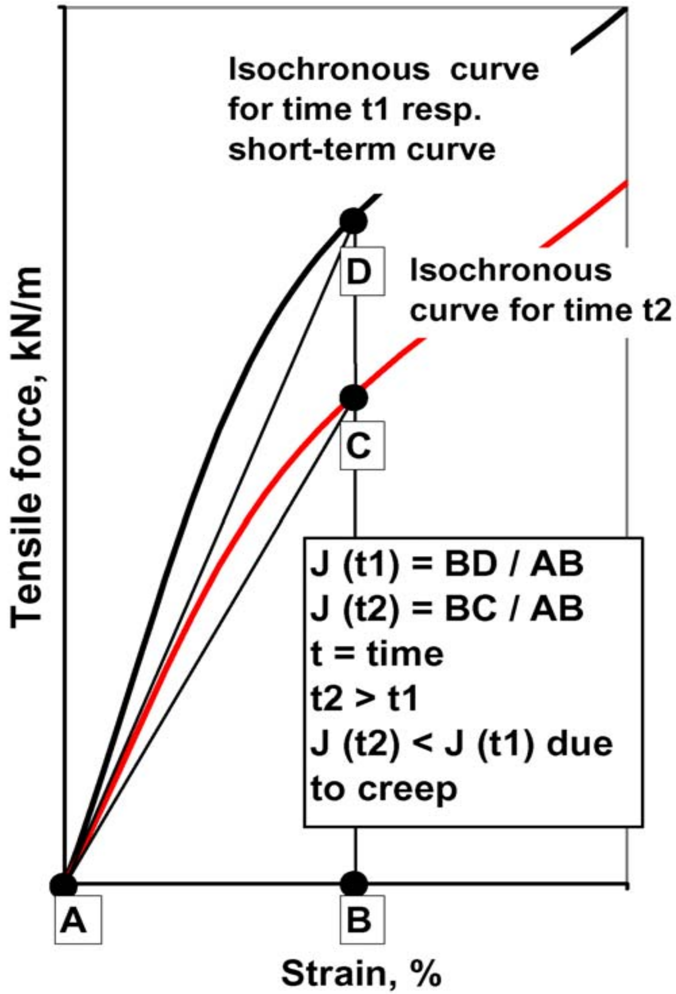
Estimation of tensile load for the allowable elongation of reinforcement ε_d

Bridging sinkholes

short-term



long-term & total via the time-dependent tensile modulus



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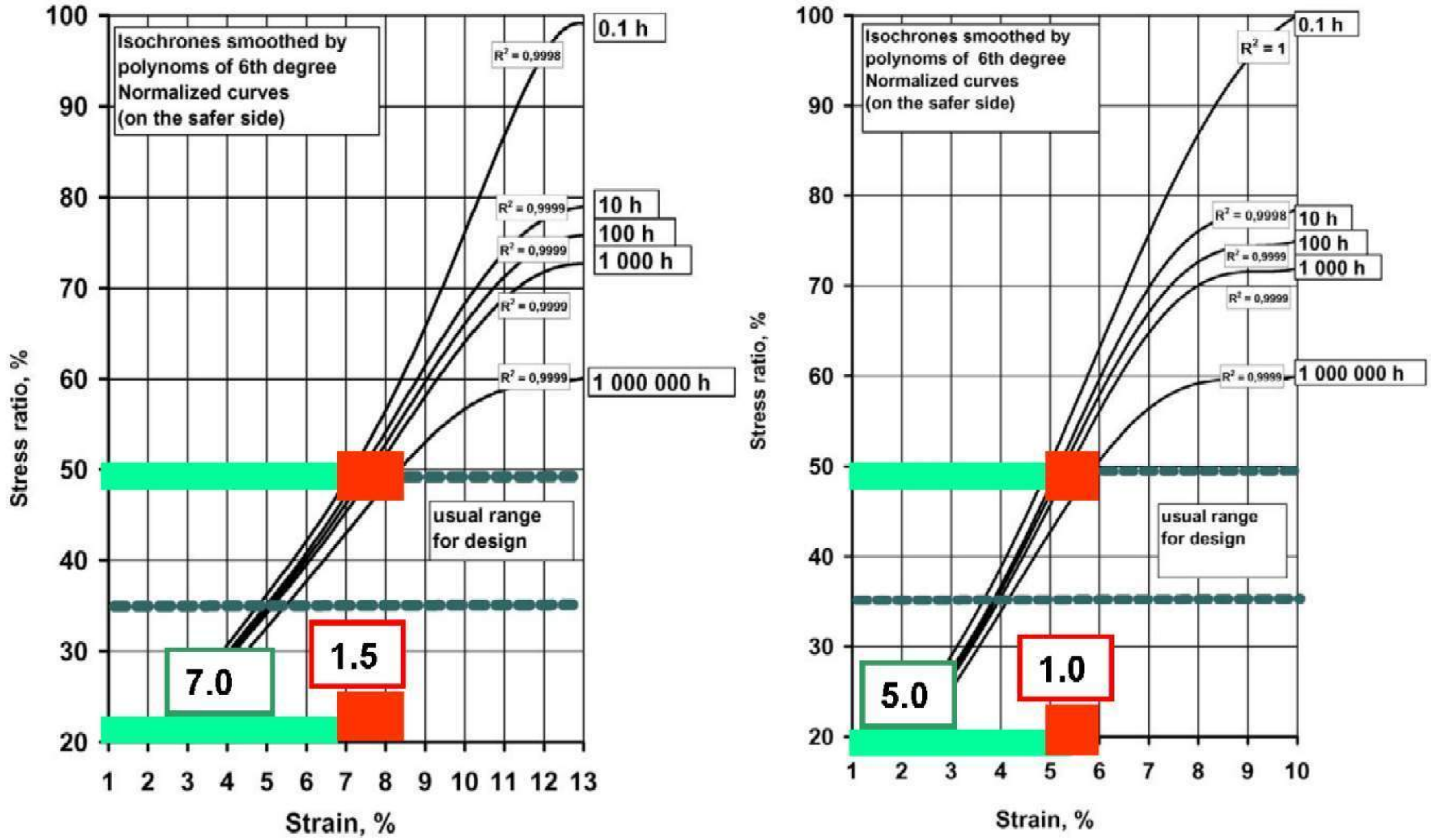
Bridging sinkholes



Strains vs. Time vs. Stress Ratio

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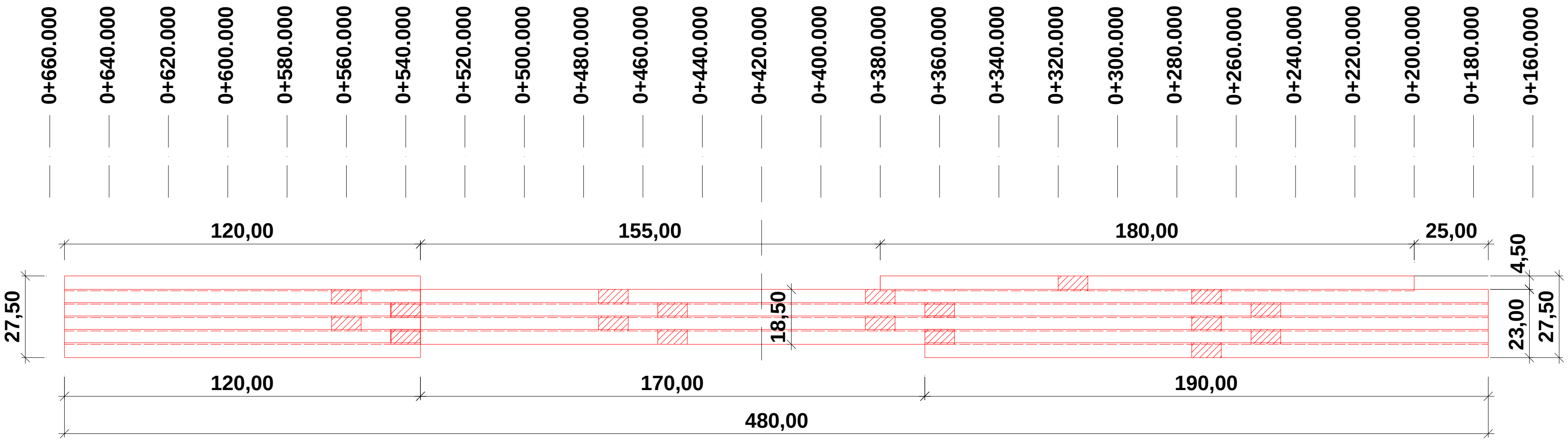
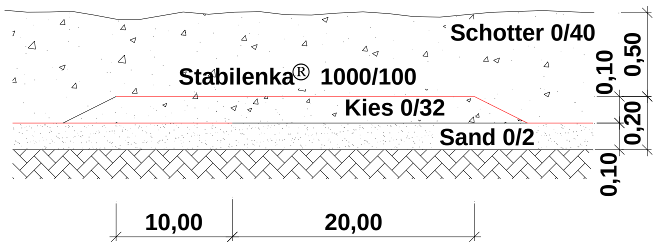
National road B 180 Bypass Zeitz–Theißen, Germany, 2000, Stabilenka 1000



Aufbau der Überlappung (schematisch)



National road B 180 Bypass Zeitz–Theißen, Germany, 2000, Stabilenka 1000

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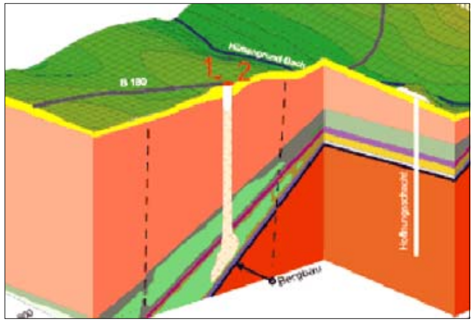
National roads B 80/B 86 Bypass Sangerhausen, Germany, 2002, 2 x Stabilenka 1000

Autobahn A 143, Germany, 2004, Fortrac® R 1200/100-10 AM

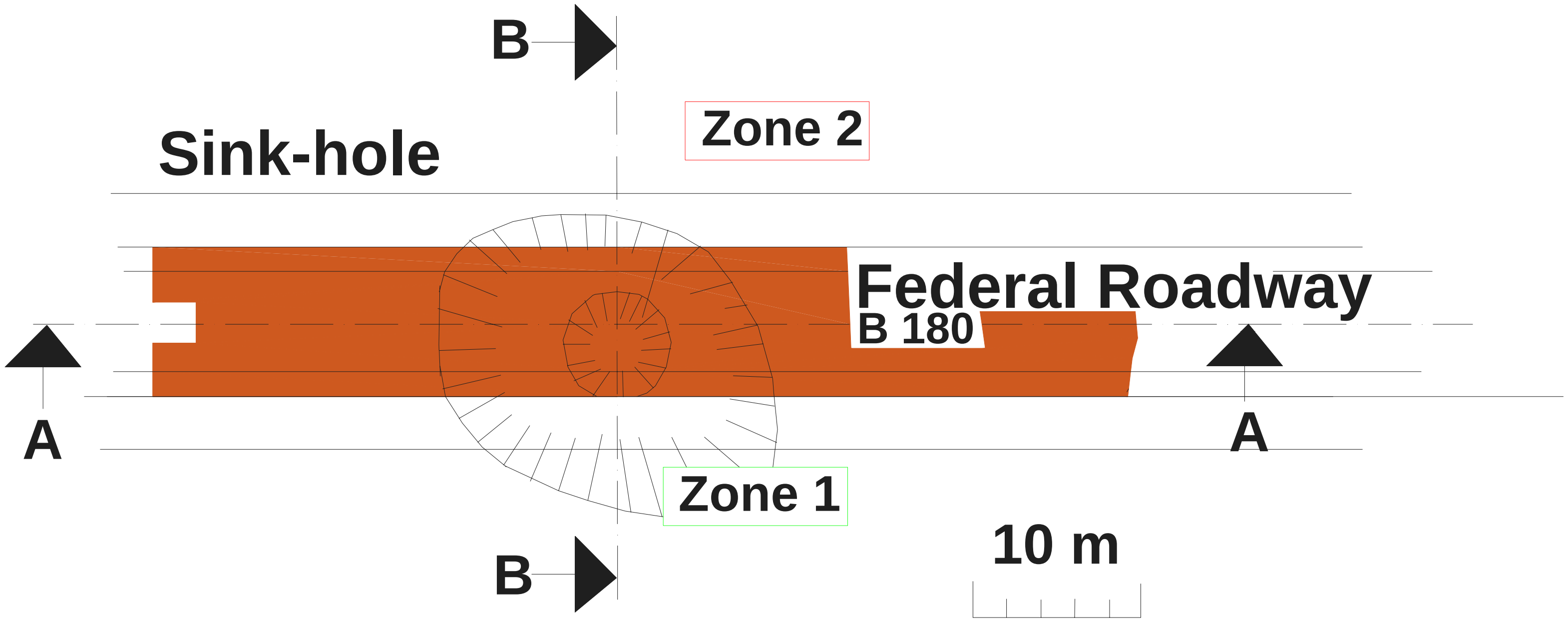
Deutsche Bahn, Gröbers, Germany, 2001, Fortrac® R 1200/100-10 AM

Deutsche Bahn, Gotha–Leinefelde, Germany, 2002, 4 to 6 x ⊥ Stabilenka® 1000/100



National road B 180,
Eisleben, Germany, 1993,
Fortrac 1200/50-10 A

Plan - view of the problem

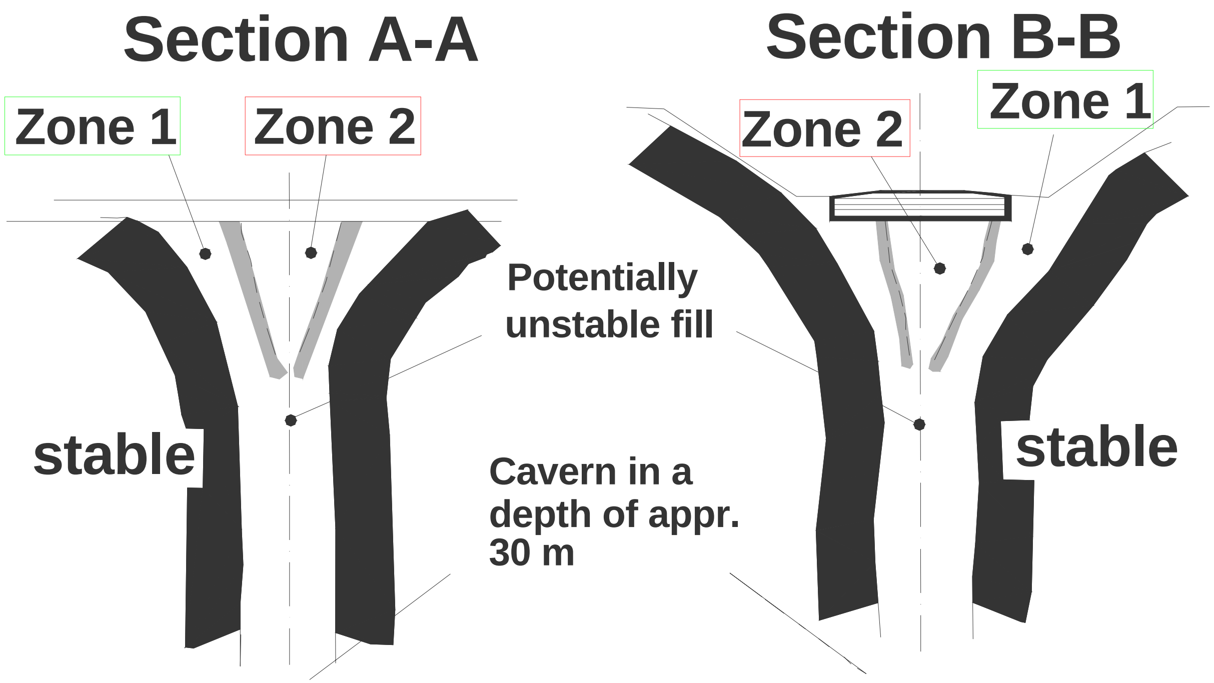


Zone 1 = lower subsidence probability
Zone 2 = higher subsidence probability

**National road B 180,
Eisleben, Germany, 1993,
Fortrac 1200/50-10 A**

Vertical cross - sections

AA - along the road axis BB - perpendicular to the road axis



Zone 1 = lower subsidence probability
Zone 2 = higher subsidence probability

National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A

Two possible solutions:

1. **Bridging RC-plate**
2. **Geosynthetics-reinforced soil body (for the first time in Germany!)**

The RC-plate was not accepted:

A. **brittle behavior („brittle" failure <u>without</u> „warning")**

B. **expansive**

C. **time-consuming**

Preference was given to the at that time very innovative geosynthetic solution:

A. **bearing capacity and sufficient serviceability even under large deformations**

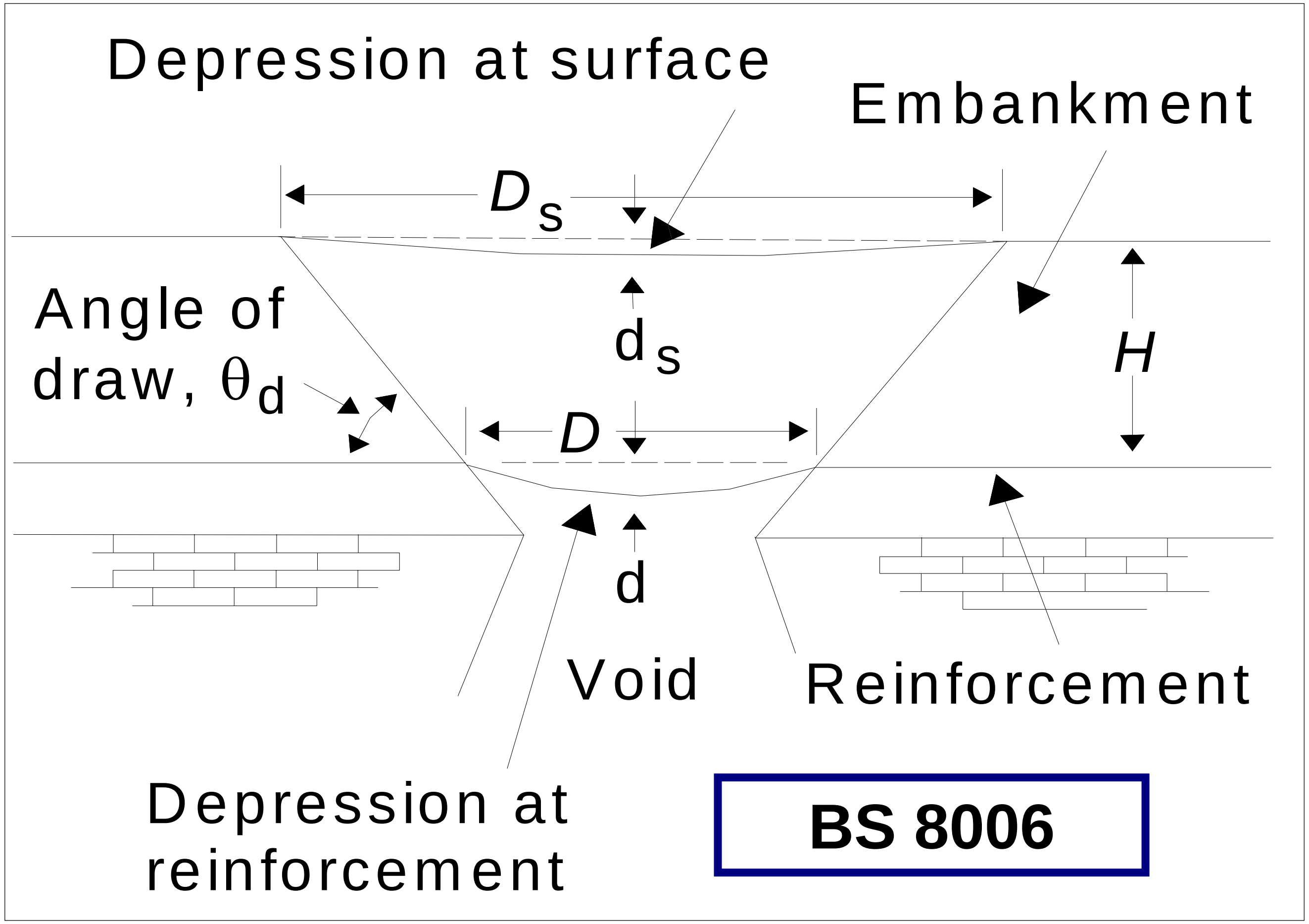
B. **ductile behavior („failure <u>with</u> warning")**

National road B 180,
Eisleben, Germany, 1993,
Fortrac 1200/50-10 A

Models available in 1993:

- „Giroud et al“ No 1 -
  very simplified and conservative
- „Giroud et al“ No 2 -
  better, but only for „thicker“ Systems; no
  Analysis of Deflection on top
- „BS 8006 Draft“ – seemed to be OK for „thin“
  Systems from non-cohesive soil,
  Analysis of deflection on top possible
- Numerical methods extremely costly and sensitive
  at that time...

National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A



National road B 180,
Eisleben, Germany, 1993,
Fortrac 1200/50-10 A

Summary of system philosophy:

1. Save the driver's life!!!

Big funnel of up to 15 m, 100 km/h, low deflection, no edges.....

2. The system should survive for about 10 minutes.

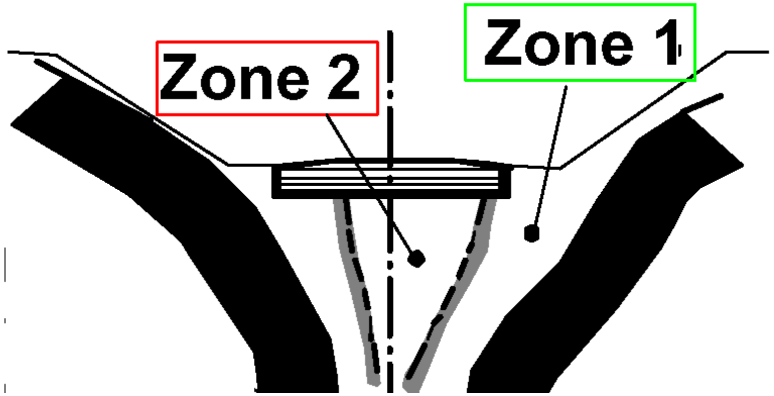
3. A special warning system should stop the traffic.

4. System in a cut: had to be very flat (thin).

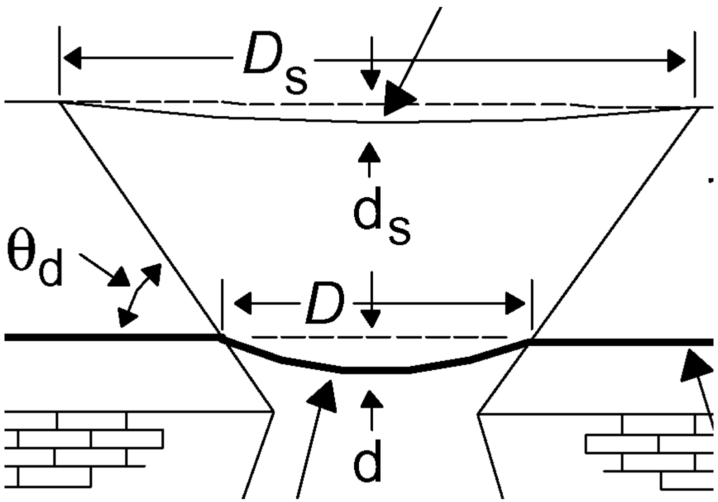
- **Concept, design and construction in 1993.**
- **Design was performed by the Engineering Department of Huesker in collaboration with the consultant in Leipzig and the officials.**
- **At that time, design calculations resulted in the new development and production of the Geogrid Fortrac® A 1200/50 10 A, which was produced and used for this project as first aramid geogrid worldwide.**
- **A more detailed project description can be found in the publication in: Alexiew D.: Bridging a sink-hole by high-strength high-modulus geogrids. *Proc. Geosynthetics'97, Long Beach, 1997. pp. 13-24*.**

National road B 180,
Eisleben, Germany, 1993,
Fortrac 1200/50-10 A

Smaller Zone 2
of high probability
in parallel and cross directions:
$d_s/D_s \leq 0{,}02 - 0{,}03$



Large Zone 1
of low probability
only in parallel direction:
$d_s/D_s \leq 0{,}06 - 0{,}07$ short-term
Automatic traffic stopping system!



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National road B 180,
Eisleben, Germany, 1993,
Fortrac 1200/50-10 A

Final results of analyses and design calculations:

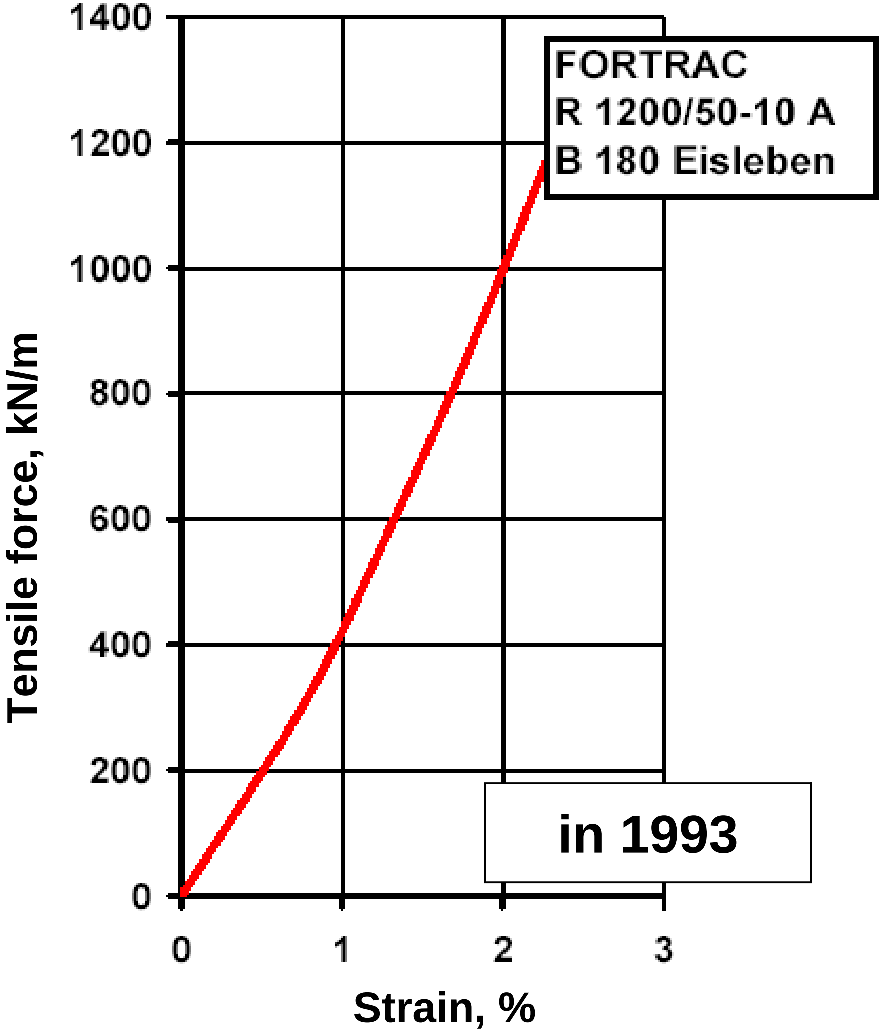
Uniaxial low-creep geogrid:

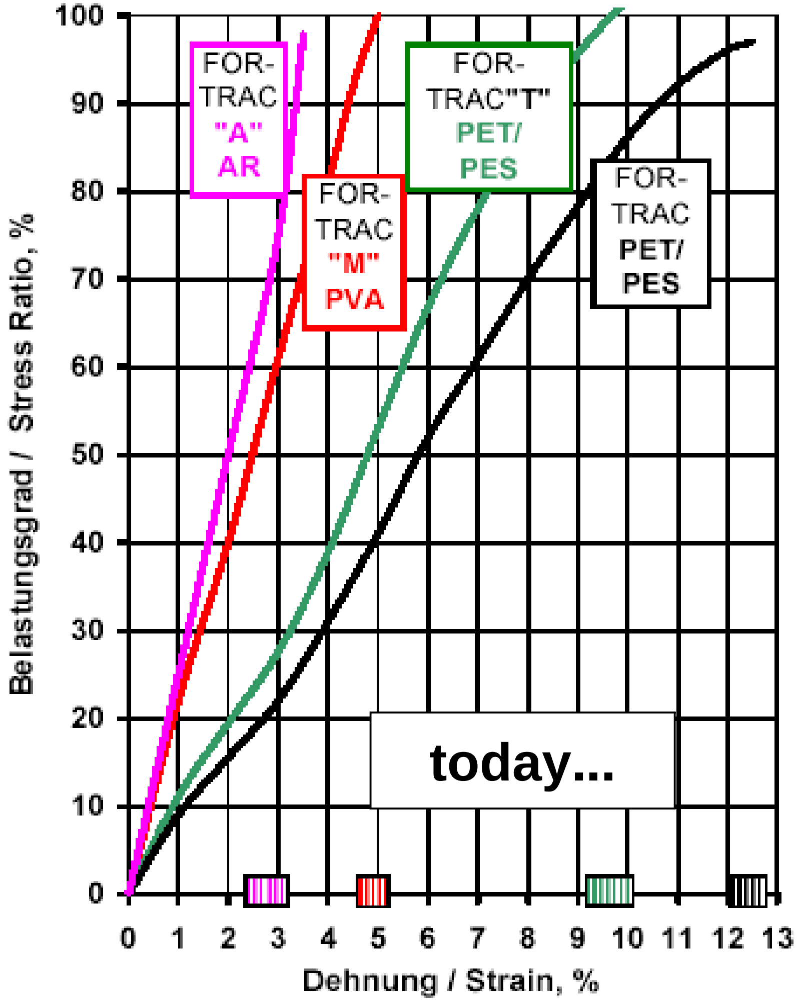
1200 kN/m at ≤ 3,0 % strain and
600 kN/m at ≤ 1,5% strain (short-term).

Was not available in 1993:
A new customized geogrid was developed, produced and tested for this project from the raw material Aramid: for the first time worldwide.

Mechanical behavior of geogrids

National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A





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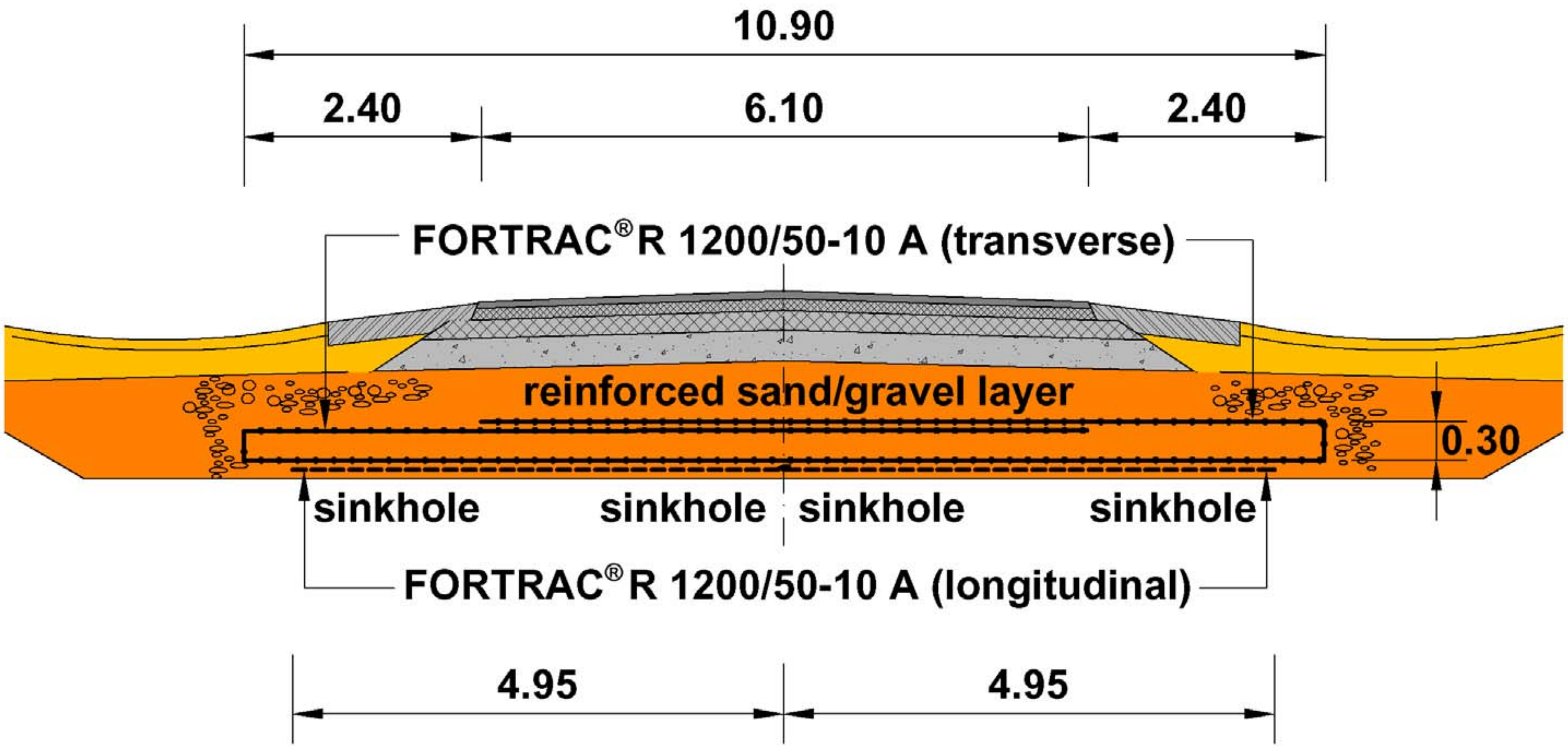
National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A



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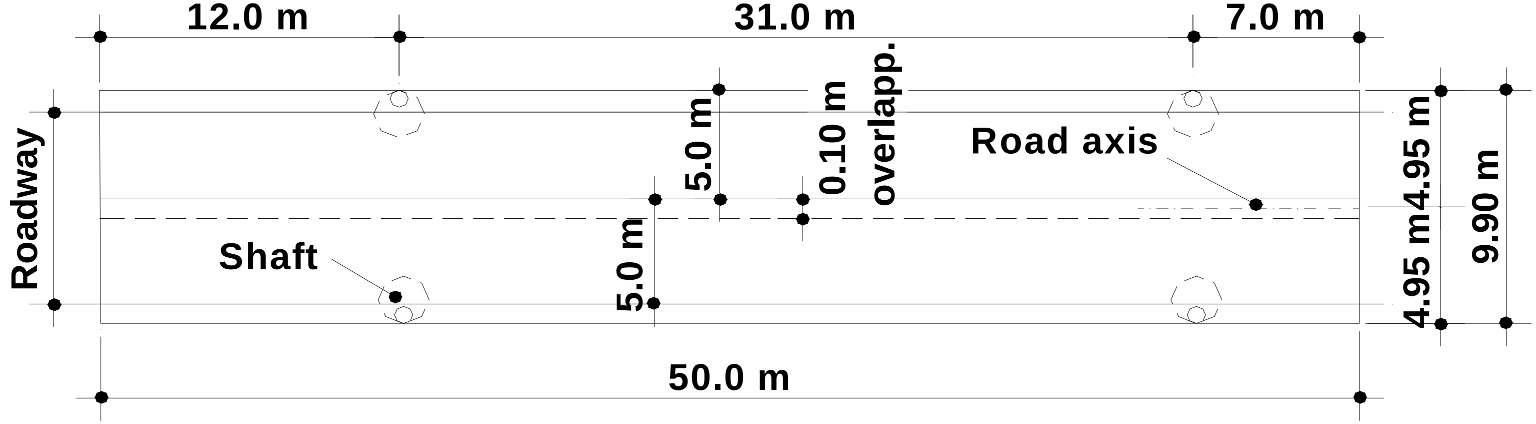
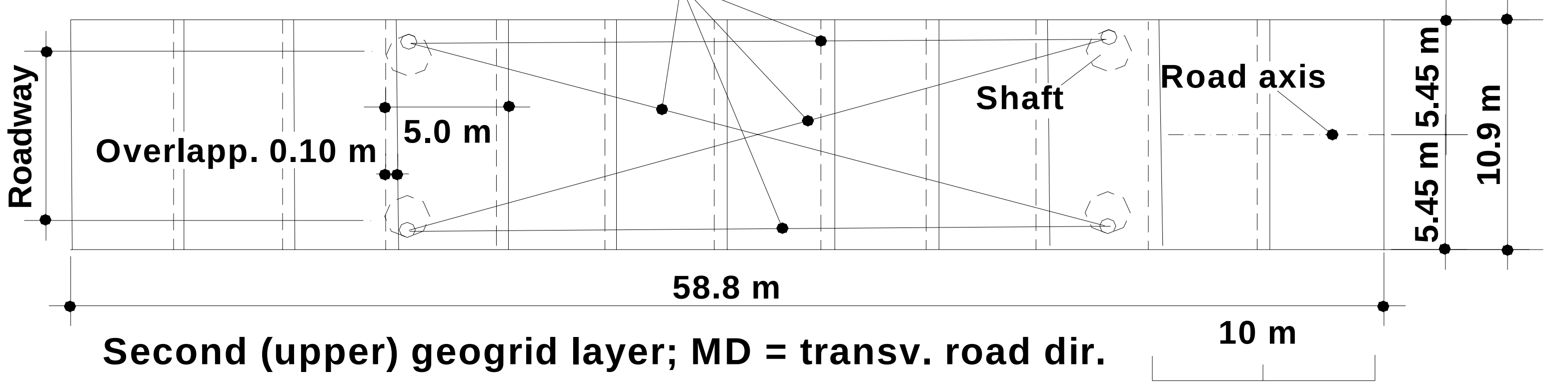
National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A



First geogrid layer; MD = road-axis direction



Second (upper) geogrid layer; MD = transv. road dir.

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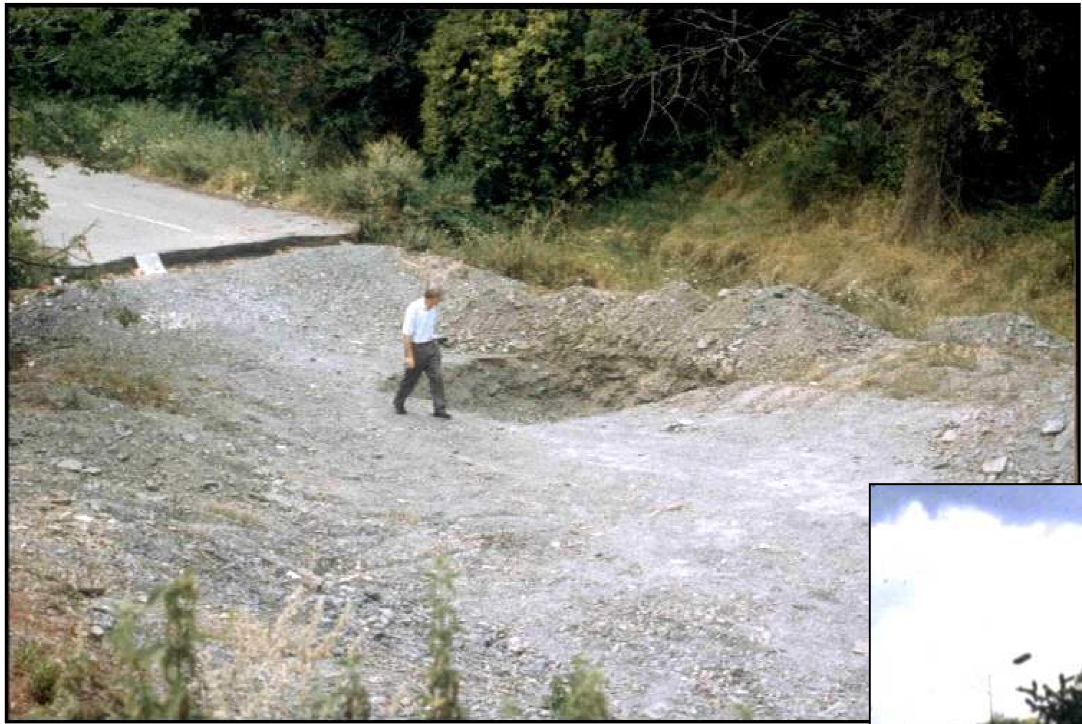
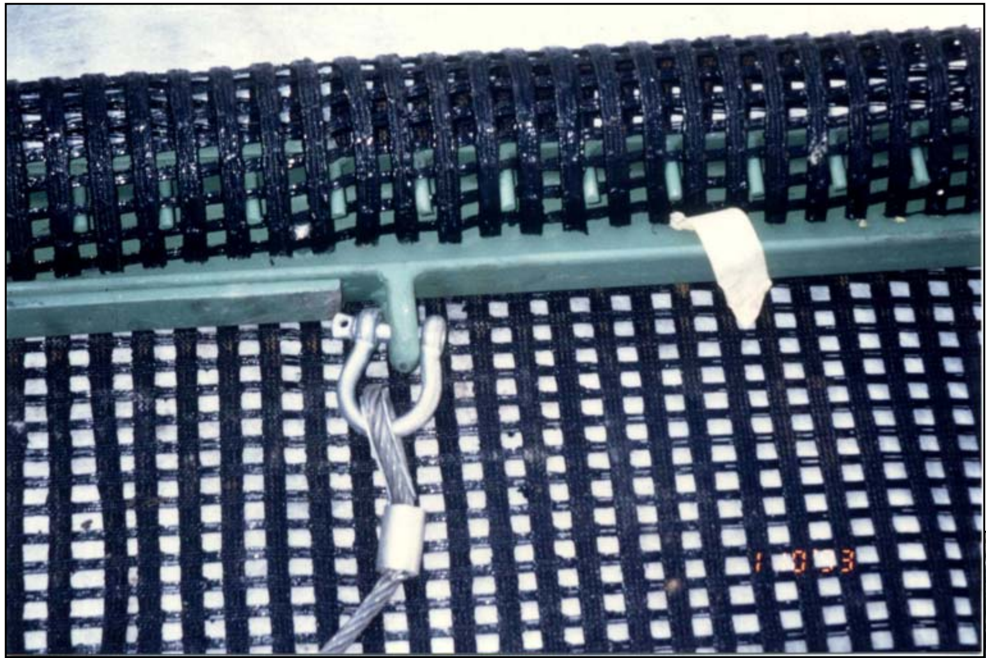
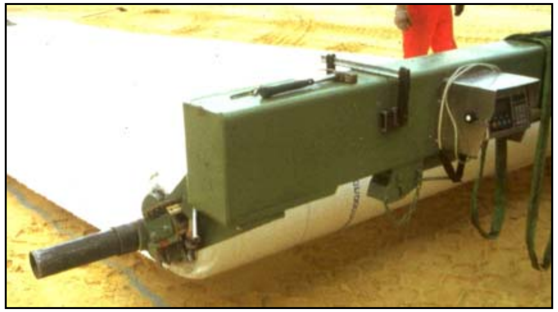
National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A



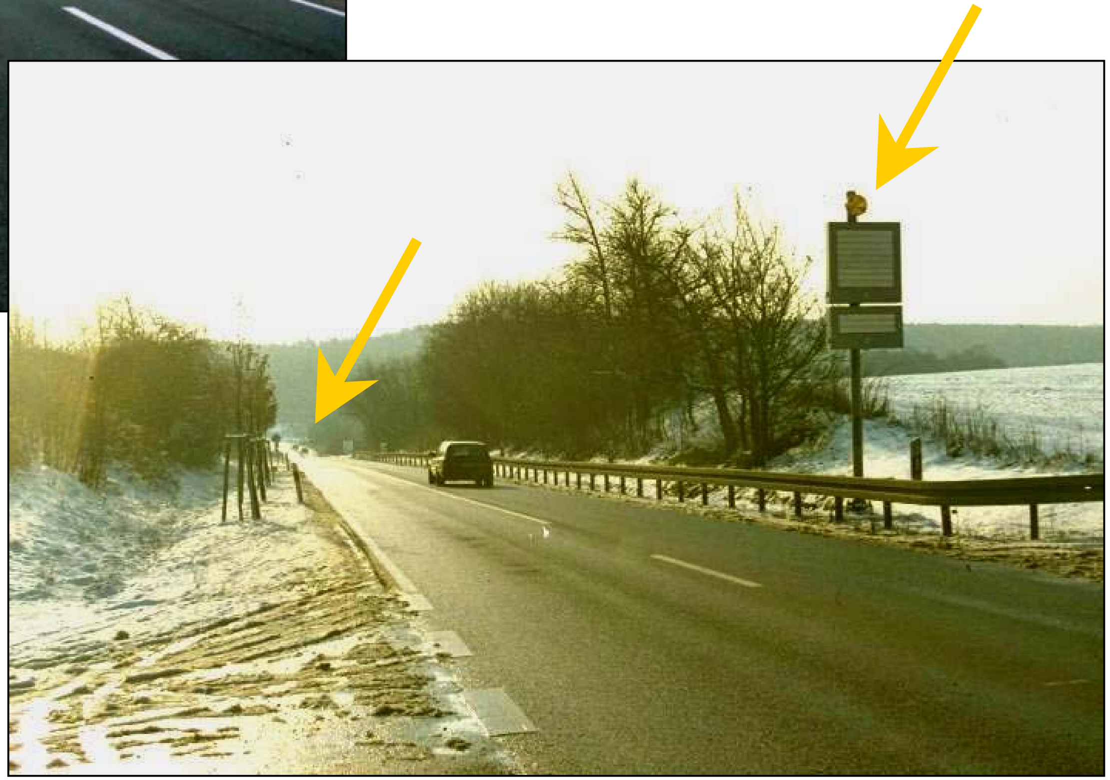
National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A



National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A



National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A



Reactivation of the sinkhole at the 17th Oct. 2001 about 6:00 p.m. (based on very deep water dam in the neighborhood it is believed that the reactivation started possibly 3 days earlier)

Summary:

18:00 Noises were registered in the neighborhood. Cut slopes on both sides start to slide. First contour of the sinkhole can be identified on the road surface.

18:30 Clear deflection of the road surface. Torsion starts step by step. Traffic is going on with 100 km/h automatic warning signs are still not activated.

18:45 Deflection increases. Still no activation of the warning signs. Eyewitnesses from the neighborhood tried to stop the traffic without any success. Traffic is going on.

19:00 People from the neighborhood and meantime the police stopp the still intensive traffic. Sinkhole funnel on a large area beneath the road. Deflection increases, longitudinal and cross inclinations also increase. A part of a slope on one side slides finally beside the road and disappeares in the funnel. Warning shields are still not activated.

19:30 Deflection and inclinations continue to increase; about that time the system collapses. The geogrids (they are not pulled out!) fail. They fail more ore less at the mid span of the funnel.

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National road B 180,
Eisleben, Germany, 1993,
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The day after...

National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A

The day after...

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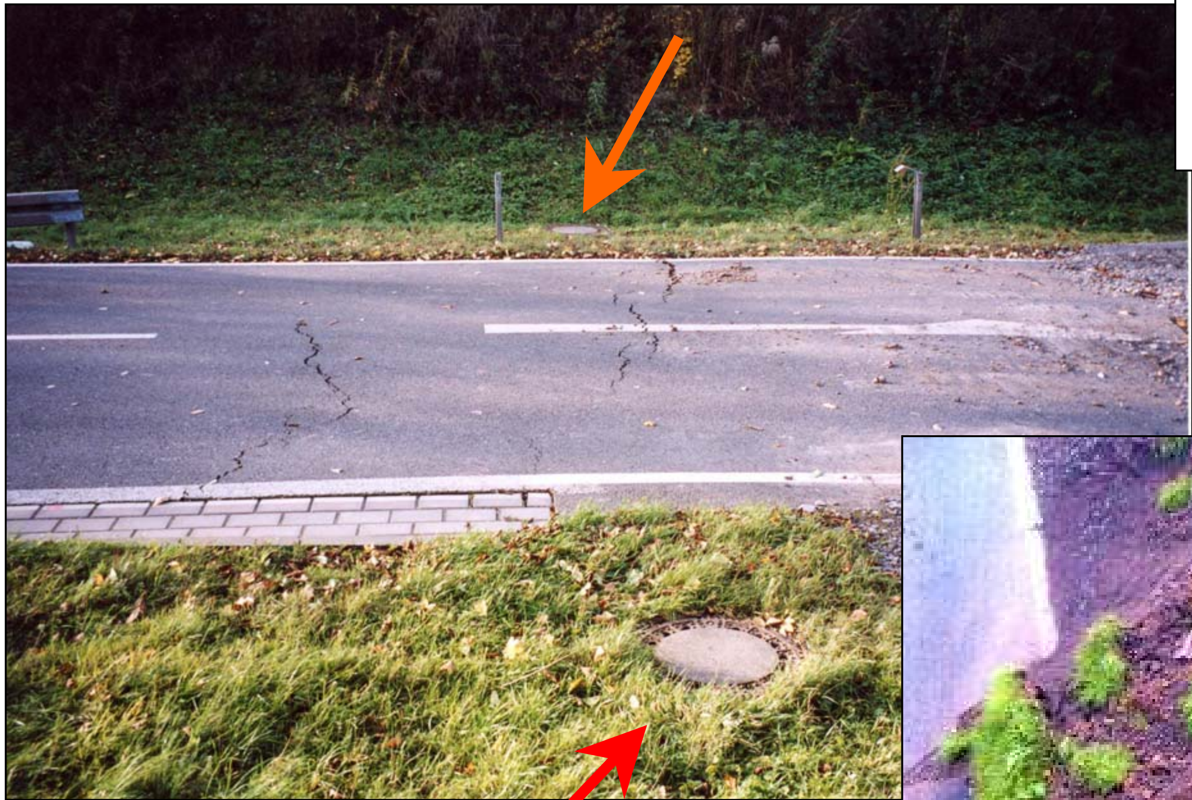
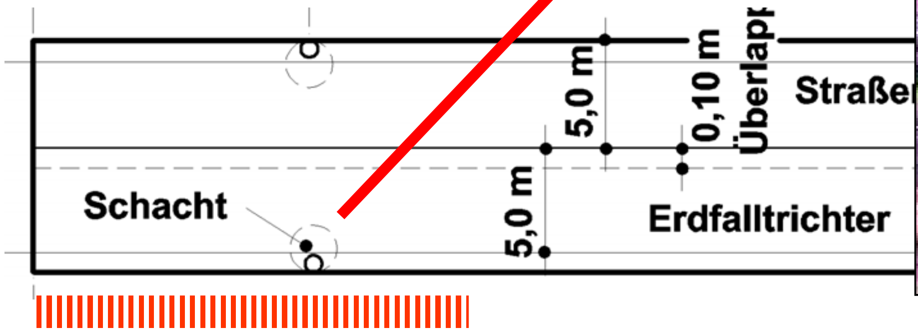
National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A





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National road B 180,
Eisleben, Germany, 1993,
Fortrac 1200/50-10 A

National road B 180, Eisleben, Germany, 1993, Fortrac 1200/50-10 A

Summary:

1. Generally, the behavior of the system was better than expected. It was developed in 1993 only for short time sinkhole bridging. At latest after ten minutes the warning shields had to stop the traffic. The general issue was to save vehicles (and lives) that are during 10 to 20 minutes just near the sinkhole.
2. The system has been designed in 1993 by the Engineering Dep. of Huesker (tensile strength, allowed strain, anchorage etc.) in a correct way.
3. The worldwide first Aramid-Geogrid-Project has been proved successfully.
4. This fact was of extreme importance due to the failure of the warning stopp shields (meantime we know that after a routine maintenance one of the technicians has forgoten to reactivate the electricity (!))

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National road B 180,
Eisleben, Germany, 1993,
Fortrac 1200/50-10 A

Summary:

5. An extremely flat system for bridging sinkholes can be accepted.
6. The additional antitorsional geogrid reinforcement (not really dimensioned) was helpful in that specific case reducing torsional deformation and holding the entire reinforced package together when the slopes beside slided down into the sinkhole.
7. Some samples from the geogrid were exhumed and tested. Only a non-relevant lost of strength and a slight increase in tensile stiffness were registered.

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National road B 180,
Eisleben, Germany, 1993,
Fortrac 1200/50-10 A

Post-History:

Two days later the sinkhole funnel was refilled due to technical and political reasons. Although a completely new modern ring-road section for Eisleben is under construction (as a general regional infrastructure project) officials tend to rebuild the system on the existing B 180 in the same way and to keep the road in operation.

The fact that the described critical dimensioning case "full sinkhole opening" became reality is very, very rare and can be compared with the case of strong earthquake or the "hundred year high tide". The "life" checking and confirmation of such a specific non-usual project by the reality is more or less unique in civil engineering.

Thank you!

Questions?