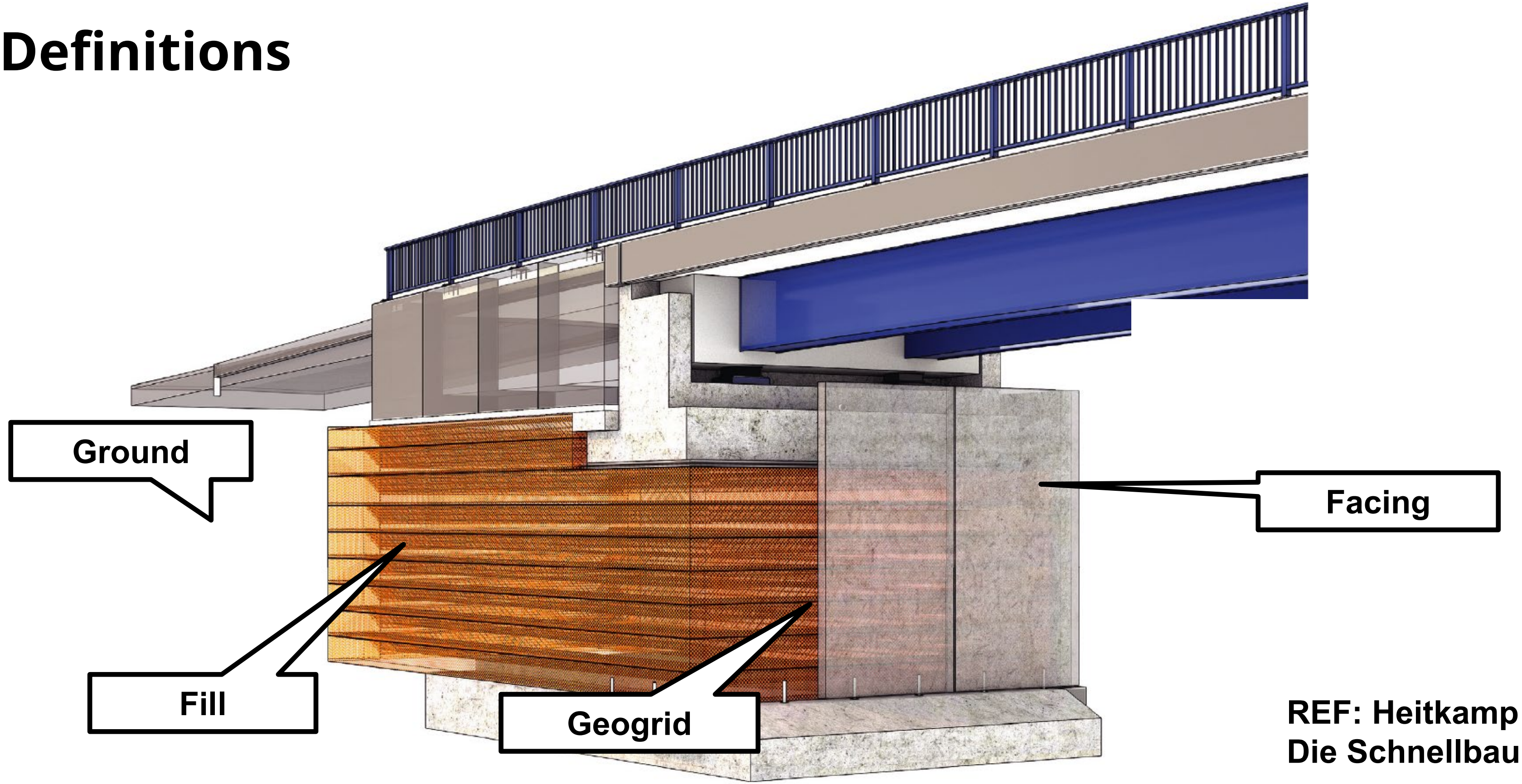
Sustainability of geogrids in MSE-Walls and bridge abutments

Dipl. Ing. Hartmut Hangen
HUESKER Synthetic GmbH

Geogrid reinforced retaining walls (MSE)

HUESKER
Ideen. Ingenieure. Innovationen.

Definitions

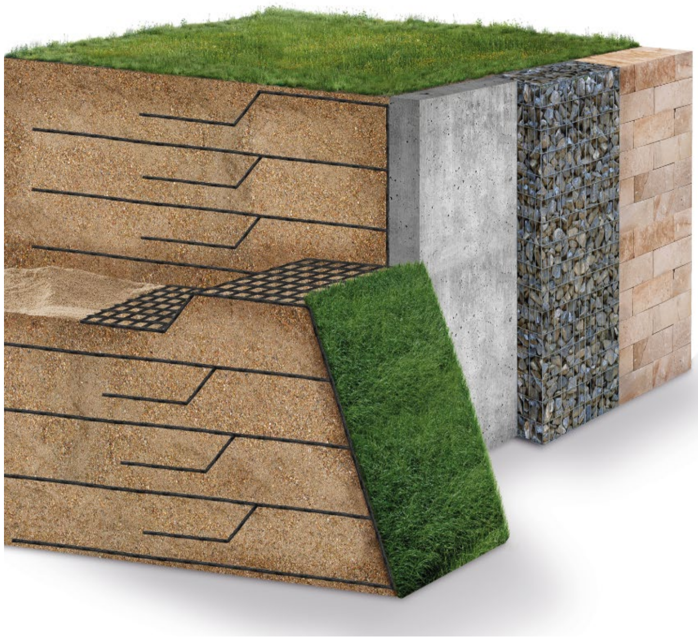


REF: Heitkamp
Die Schnellbaubrücke

WHY should I care about this technology?

HUESKER
Ideen. Ingenieure. Innovationen.

The specific benefits



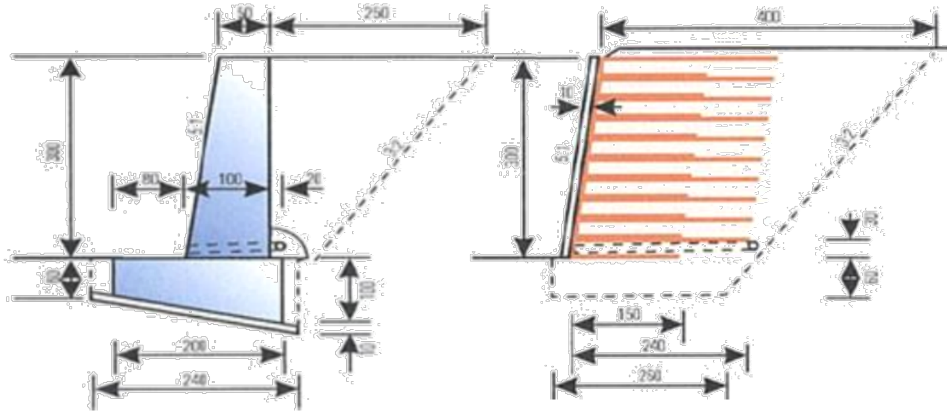
Fast and long-term safe construction	Modular, economical systems	Construction also possible with cohesive and contaminated soils
Building heights over 60 m and inclinations with 110º possible	Time-consuming foundation can be avoided	Space and material savings due to steep slopes
	Less CO2 emissions, lower energy consumption than conventional construction methods	Resource-saving through use of excavated material/soil

EAGM European Association of Geosynthetic product Manufacturers

COMPARATIVE LCA OF GEOSYNTHETICS versus CONVENTIONAL CONSTRUCTION MATERIALS
CASE 4: SOIL RETAINING WALL

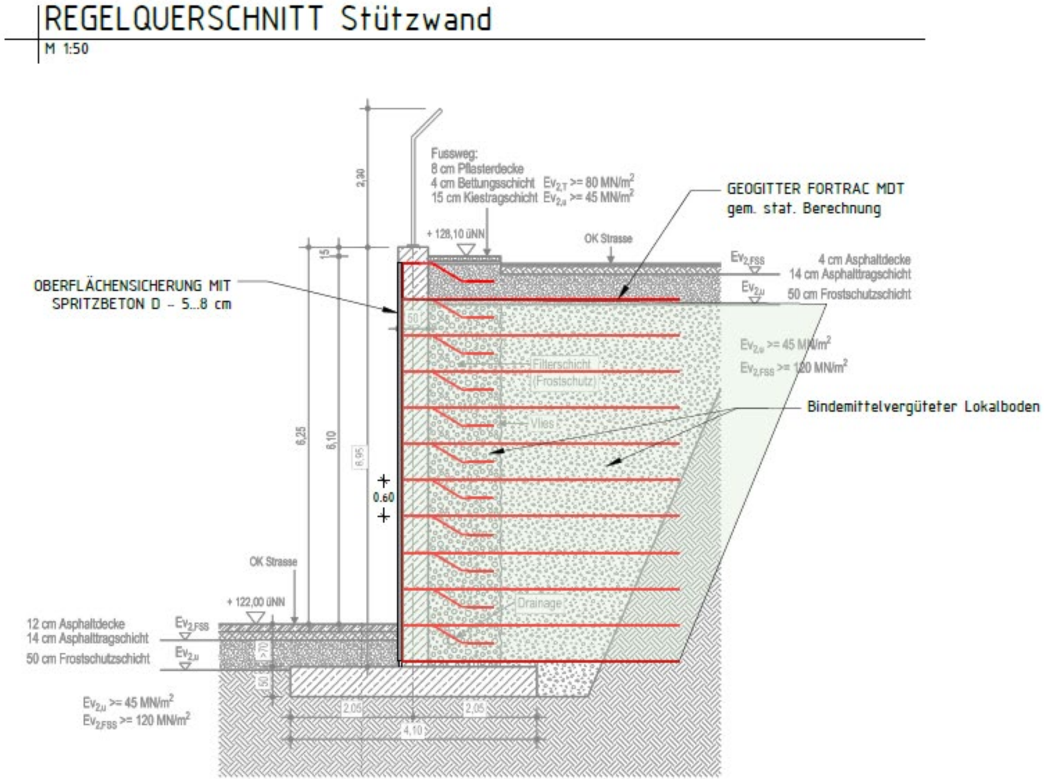
EAGM-case study - CASE 4: Soil retaining wall

Specification of soil retaining wall



Schematic cross-section of retaining walls: the reinforced concrete wall (CASE 4A, left) versus the geosynthetic reinforced wall (CASE 4B, right)

Parameter	Unit	CASE 4A - conventional -	CASE 4B - geosynthetics -
wall length	m	50	
wall height	m	3	
excavation foundation	m³	109	-
base compaction	m²	121	262
formwork foundation	m²	83	-
blinding layer	m²	120	-
concrete foundation	m³	80	-
foundation reinforcement	kg	2.400	-
formwork wall face	m²	153	-
formwork wall coarse	m²	150	-
concrete wall	m³	105	-
wall reinforcement	kg	5.250	-
building gaps	m²	21	-
drainage	m	62	72
filter gravel	m³	10	11
frost wall backfilling	m³	219	-
backfill compaction	m²	500	-
sub-base excavation	m³	-	79
sub-base fill material	m³	-	79
formwork support	m²	-	153
geosynthetics delivery and laying	m²	-	1960
wall embankment	m³	-	480
layer compaction	m²	-	1.550
shotcrete lining	m²	-	155
cover material	m³	-	45


REGELQUERSCHNITT Stützwand
M 1:50
Fussweg:
8 cm Pflasterdecke
4 cm Bettungsschicht $Ev_{2,T}$ >= 80 MN/m²
15 cm Kiestragschicht $Ev_{2,u}$ >= 45 MN/m²
GEOGITTER FORTRAC MDT
gem. stat. Berechnung
+ 128,10 üNN
OK Strasse
OBERFLÄCHENSICHERUNG MIT
SPRITZBETON D – 5...8 cm
$Ev_{2,FSS}$
4 cm Asphaltdecke
14 cm Asphalttragschicht
$Ev_{2,u}$
50 cm Frostschutzschicht
$Ev_{2,u}$ >= 45 MN/m²
$Ev_{2,FSS}$ >= 120 MN/m²
Filterschicht
(Frostschutz)
Vlies
Bindemittelvergüteter Lokalboden
0.60
Drainage
OK Strasse
+ 122,00 üNN
12 cm Asphaltdecke
14 cm Asphalttragschicht
50 cm Frostschutzschicht
$Ev_{2,u}$ >= 45 MN/m²
$Ev_{2,FSS}$ >= 120 MN/m²
2,30
15
6,25
6,10
6,95
2,05
2,05
4,10

CASE 4: Soil retaining wall

HUESKER
Ideen. Ingenieure. Innovationen.

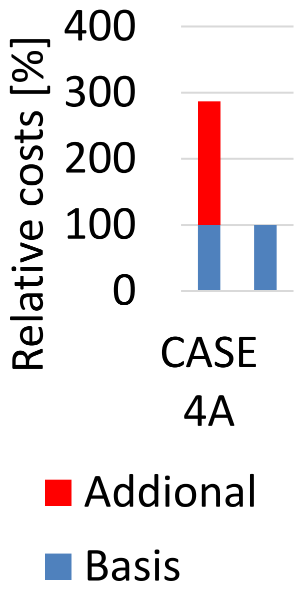
		CASE 3A - conventional -			CASE 3B - geosynthetics -		
	Unit	Unit	Unit price	Costs	Unit	Unit price	Costs
Site preparation	Pcs.	1.0	€ 4,692.00	€ 4,692.00	1.0	€ 4,692.00	€ 4,692.00
Excavate soil for foundation and store temporarily in construction site area	m³	109	€ 4.49	€ 489.59	79	€ 4.49	€ 354.84
Construct and compact foundation base	m²	121	€ 1.51	€ 182.41	-	-	-
Supply, install and compact soil replacement for foundation	m³	-	-	-	79	€ 15.35	€ 1,212.62
Supply and install blinding layer	m²	120	€ 12.86	€ 1,542.84	-	-	-
Supply and install foundation formwork	m²	83	€ 33.55	€ 2,784.28	-	-	-
Supply and lay steel reinforcing mesh cut and bent for foundation	t	2.4	€ 1,933.92	€ 4,641.40			
Supply and install foundation concrete	m³	80	€ 220.11	€ 17,608.80			
Supply and install large-area formwork for outer face of retaining wall	m²	153	€ 17.03	€ 2,604.94			
Supply and install large-area formwork for inner face of retaining wall	m²	150	€ 17.03	€ 2,553.86			
Supply and install steel reinforcing mesh cut and bent for foundation	t	05:25	€ 1,945.42	€10,213.44			
Supply and install geogrid	m²				1.960	€ 4.83	€ 9,459.29
Supply and install concrete for retaining wall	m³	105	228.97	€ 24,041.33			
Close sound holes	Pcs.	21	€ 183.85	€ 3,860.78			
Supply and apply bitumen sealing	m²	154	14.55	€ 2,240.32			
Supply and install drainage pipe	m	62	€ 17.50	€ 1,084.85	72	€ 17.50	€ 1,259.82
Supply and install granular filter	m³	10	€ 24.00	€ 240.03	11	€ 24.00	€ 264.04
Supply and place backfill	m³	219	€ 10.38	€ 2,272.78	480	€ 11.80	€ 5,665.99
Supply and place cover soil	m³				45	€ 98.11	€ 4,414.94
Supply and apply shotcrete for front face	m²				155	€ 26.02	€ 4,032.79

CASE 4: Soil retaining wall

HUESKER
Ideen. Ingenieure. Innovationen.

	CASE 4A - conventional -	CASE 4B - geosynthetics -
Site preparation	€ 4,692.00	€ 4,692.00
Preparatory work	**€ 489.59**	**€ 354.84**
Foundation work	**€ 26,759.72**	**€ 1,212.62**
Retaining structure	**€ 49,112.32**	**€ 25,096.87**
Total costs (excl. site preparation)	**€ 76,361.62**	**€ 26,664.32**
Cost comparison	**286 %**	**100 %**

508,3 €/m²



177,7 €/m²

Ecological

Sustainability of Geosynthetics

Life cycle impact Infrastructure element

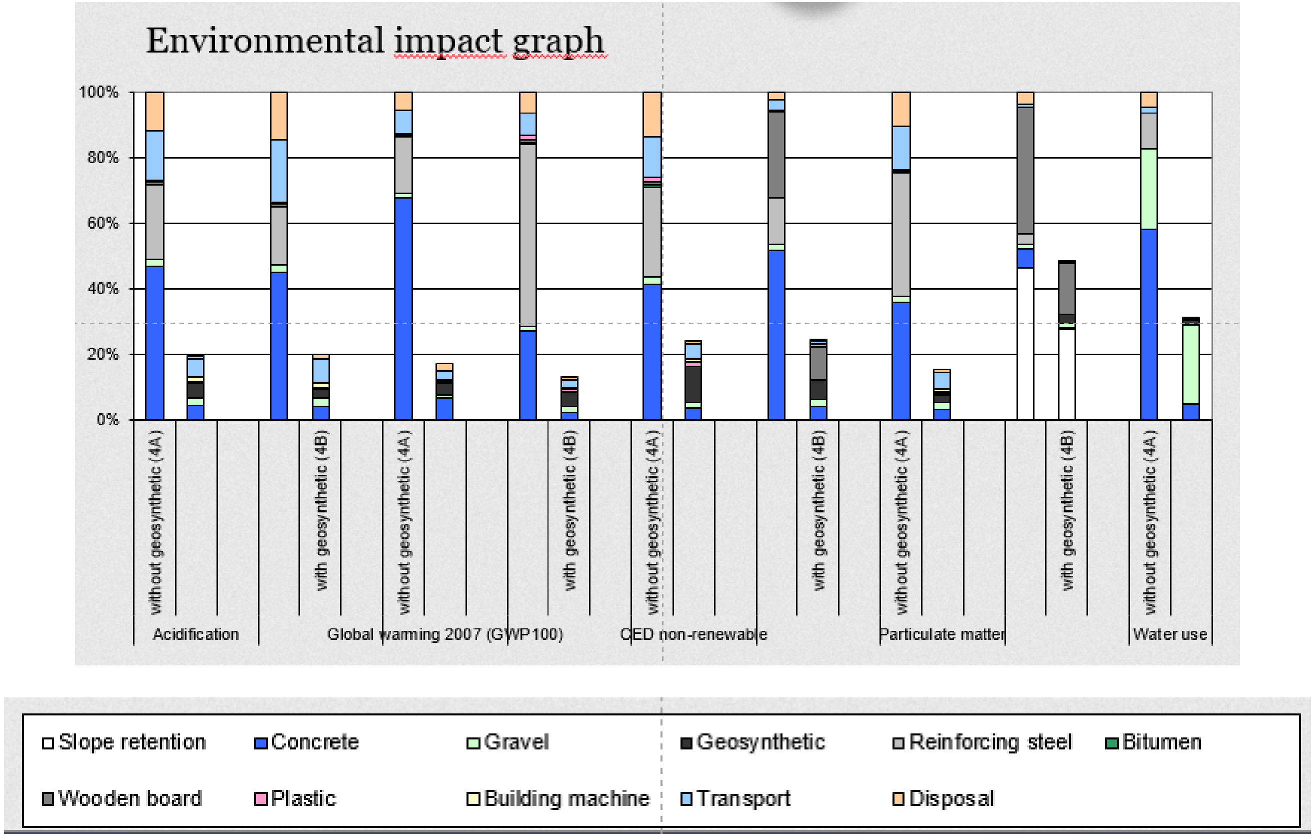
HUESKER
Ideen. Ingenieure. Innovationen.

Selected key figures referring to the construction of reinforced concrete wall (4A) and geosynthetic reinforced soil structure (4B)

	Unit	4A Concrete	4B Geosynthetics
Concrete, sole plate and foundation	m^3/m	1.60	-
Lean mix concrete	m^3/m	0.24	-
Structural concrete	m^3/m	2.10	0.31
Reinforcing Steel	kg/m	153	-
Geosynthetic	m^2/m	-	39.2
Diesel in building machine	MJ/m	11.6	53.9
Transport, lorry	tkm/m	701	265
Transport, freight, rail	tkm/m	33.2	6.9
NMVOC emissions (bitumen)	g/m	20	-

Indicators investigated: Acidification, Eutrophication, Global Warming, Photochemical oxidation, CED non-renewable, CED renewable, Particulate matter, Land competition & Water use

Environmental impact graph



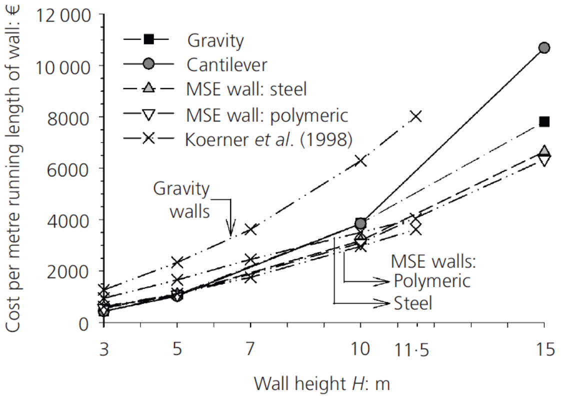
THIS STUDY SHOWS

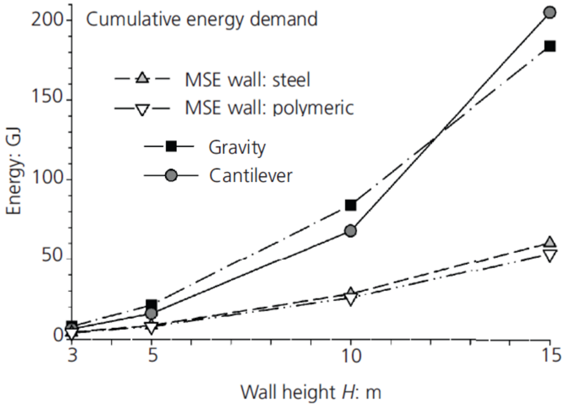
The use of geosynthetics leads to:

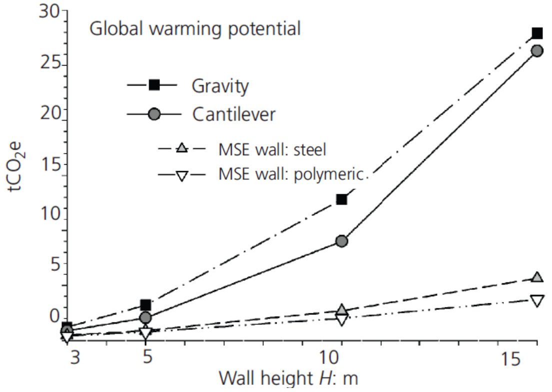
- **lower impact in all categories**
- **~ 75% reduction of Non renewable cumulative energy demand (CED)**
- **~ 85% reduction of cumulative greenhouse gas emissions**
- **Every 3 linear meters soil retaining wall (3 meter high) saves 30,000 MJ eq, which is equivalent to the energy consumption of one household per year!**

The whole study including the results of the critical reviews is available on:
http://www.eagm.eu/

Sustainability







cost

energy

CO_2 equivalent

Damians et al. 2018

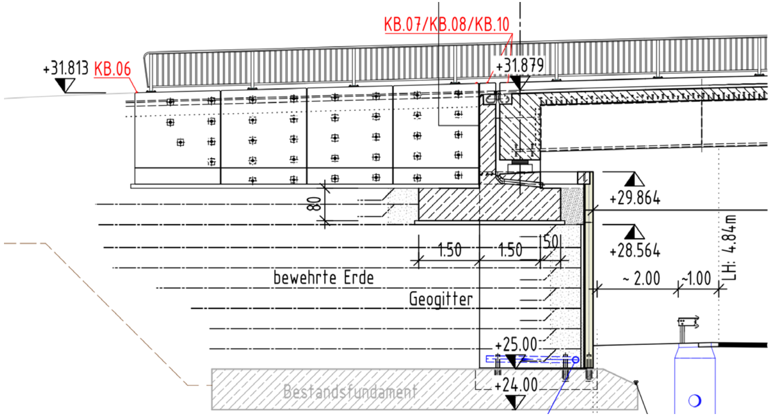
More focused on bridge abutments?

Pilot project „Stokkumer Straße“, Germany

HUESKER
Ideen. Ingenieure. Innovationen.

- Use of the existing foundations
- Geosynthetic-reinforced soil
- Reinforced concrete beam with chamber wall
- Precast reinforced concrete elements as facing elements
  - Interstitial filling with expanded clay
  - Bracing by U-shaped in-situ concrete beam

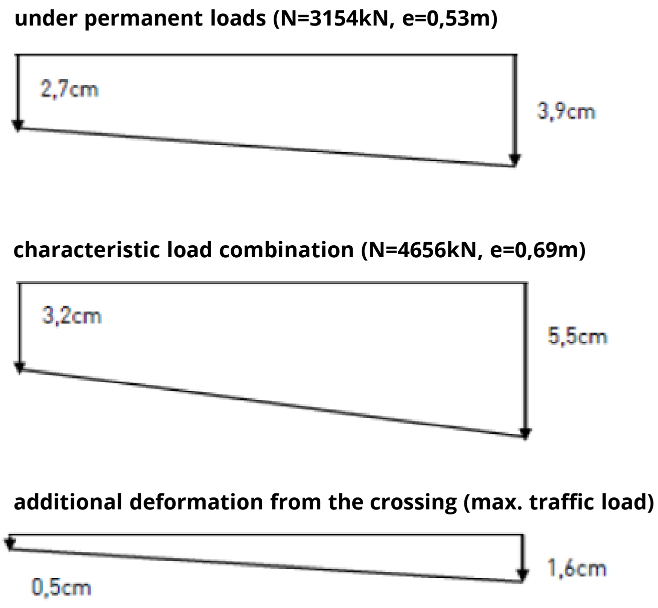
- Wing walls through precast cantilever walls
- Lateral gabion facing



Boundary conditions – load-bearing capacity and serviceability

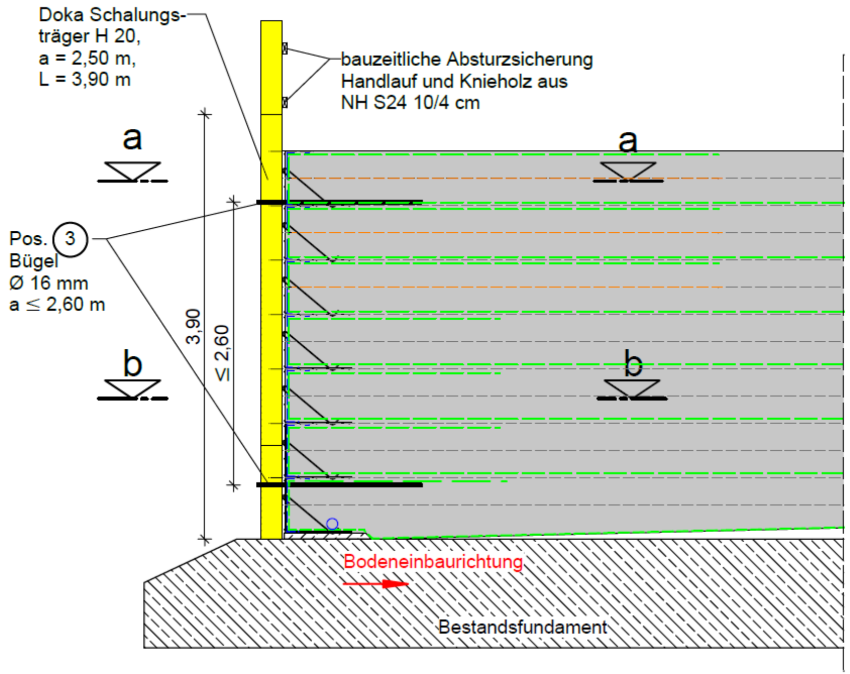
- Construction height (GRS): ca. 4 m
- Distance abutment beam / edge of slope = 0,5 m
- Surcharge voltage in substitute surface a‘ x b‘ = 585 kN/m

- Measures / Determinations:
  - Deformation calculation with FEM (Plaxis)
  - Qual. Soil improvement with mixed binder
  - High tensile strength, and stiffness, alkali-resistant geogrid (PVA)
  - Compaction....
  - Consideration in dimensioning the bearings
  - Monitoring programme



Results of deformation analysis.

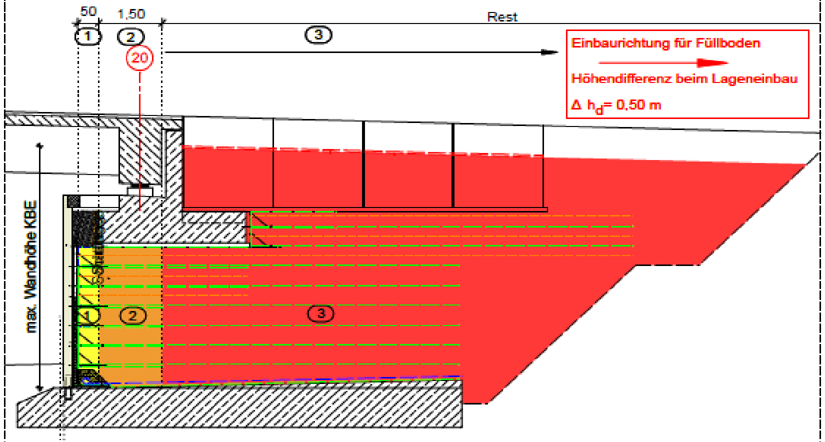
Lost, integrated formwork



Compaction in layers

ZULÄSSIGE GERÄTEBELASTUNG

für Verdichtung



Verdichtung					
Bereich	Beschreibung	zulässige Lasten	Breite	Lagenhöhe	Arbeitsweise
1	Front nur mit Rüttelplatte	G ≤ 0,1 t	b = 0,5 m	d = 0,10...0,15 m	dynamisch
2	Zwischenbereich nur mit Rüttelplatte	G ≤ 0,5 t	b ≥ 1,5 m	d = 0,25 m	dynamisch
3	Hinterfüllbereich Walze, dynamische / statische Betriebsart	G ≤ 12,5 t	ab Bandagenbreite b ≥ 2,0 m	d ≤ 0,50 m	statisch / dynamisch

Installation

Lift and transport of bridge deck

Installation

Crossing the centre line

Installation

HUESKER
Ideen. Ingenieure. Innovationen.

Lift and positioning of bridge deck

Pilot project Stokkumer Straße, Emmerich

Short construction time

- No restriction of traffic on the A3 motorway during the construction work
- **Two full weekend closures** of the A3 motorway
  - 20. to 23.09.2019 Construction demolition
  - 22. to 25.11.2019 Retracting the superstructure and completion

Flexible

Design

Execution

Cost-attractive

Pilot project Stokkumer Straße, Emmerich - LCA

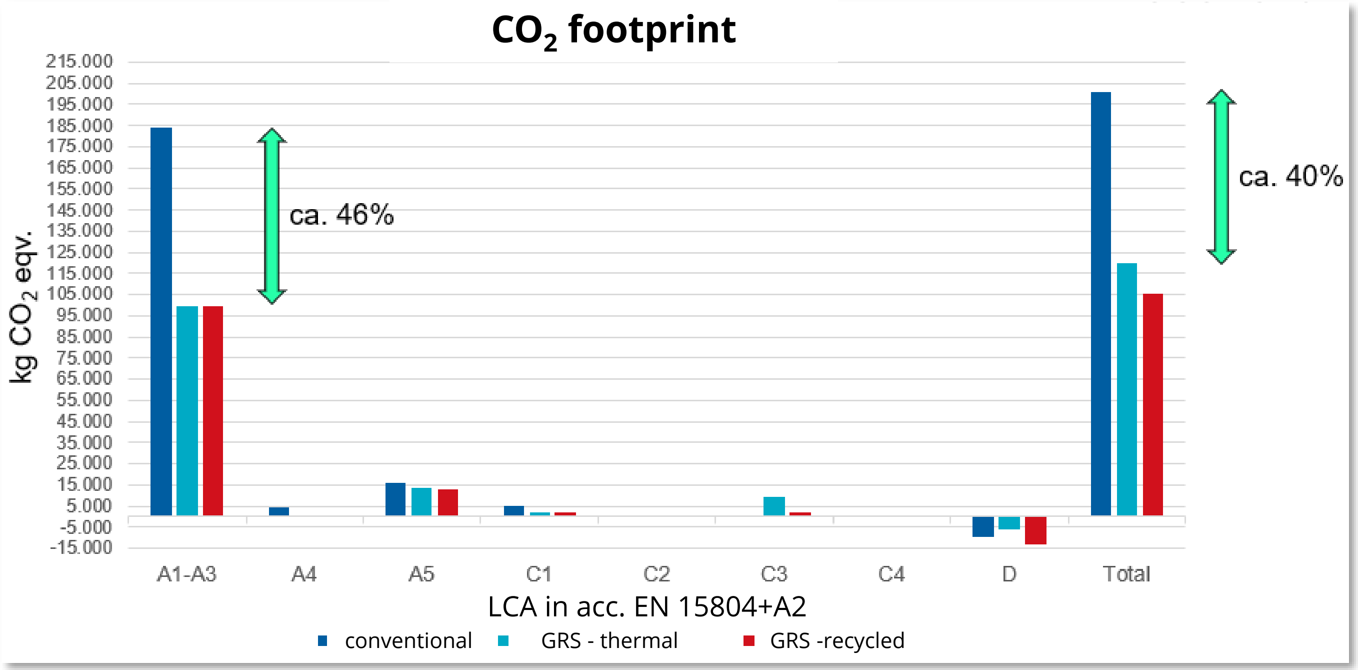
- Conventional reinforced concrete abutment
- Geogrid reinforced abutment (MSE)

Reference: Prof. Dr.-Ing. Frank Heimbecher, Raoul Mancke, M.Sc. Nachhaltige Brückensysteme mit KBE-Widerlagern – Ökobilanz im Vergleich

Pilot project Stokkumer Straße, Emmerich - LCA

HUESKER
Ideen. Ingenieure. Innovationen.

FH MÜNSTER
University of Applied Sciences



Reference : Prof. Dr.-Ing. Frank Heimbecher, Raoul Mancke, M.Sc. Nachhaltige Brückensysteme mit KBE-Widerlagern – Ökobilanz im Vergleich

Pilot project Stokkumer Straße, Emmerich - LCA

FH MÜNSTER
University of Applied Sciences

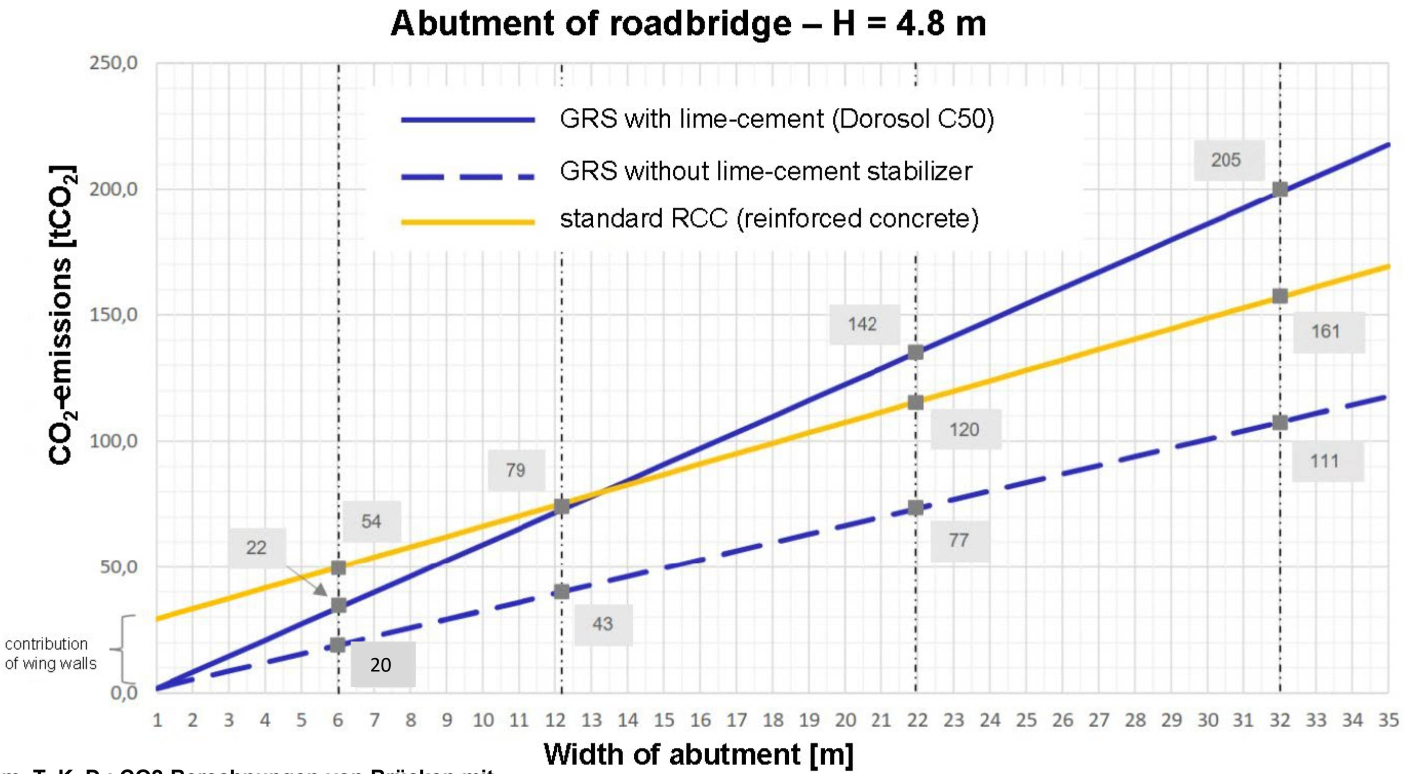
- For all abutment structures, the core environmental indicators dominate in life cycle phases A1 to A3, i.e. for the manufacture of the products, building materials incl. extraction and supply of raw materials.

- **ca. 40%** CO_2 reduction in the construction of abutments with GRS instead of conventional constructions
- **ca. 46 %** CO_2 reduction for production phases A1 to A3
- **ca. 20 %** CO_2 reduction in the absence of soil improvers

- Minimal interference with the traffic area through the use of a special formwork system made of pre-bent steel mesh mats

Reference : Prof. Dr.-Ing. Frank Heimbecher, Raoul Mancke, M.Sc. Nachhaltige Brückensysteme mit KBE-Widerlagern – Ökobilanz im Vergleich

Sustainability – university Kiel



Quelle: Görtz, S.; Pham, T. K. D.: CO2-Berechnungen von Brücken mit Bauwerkslängen bis 40 m. Bautechnik Jahrgang 101, Februar 2024, (übersetzt: Hangen)

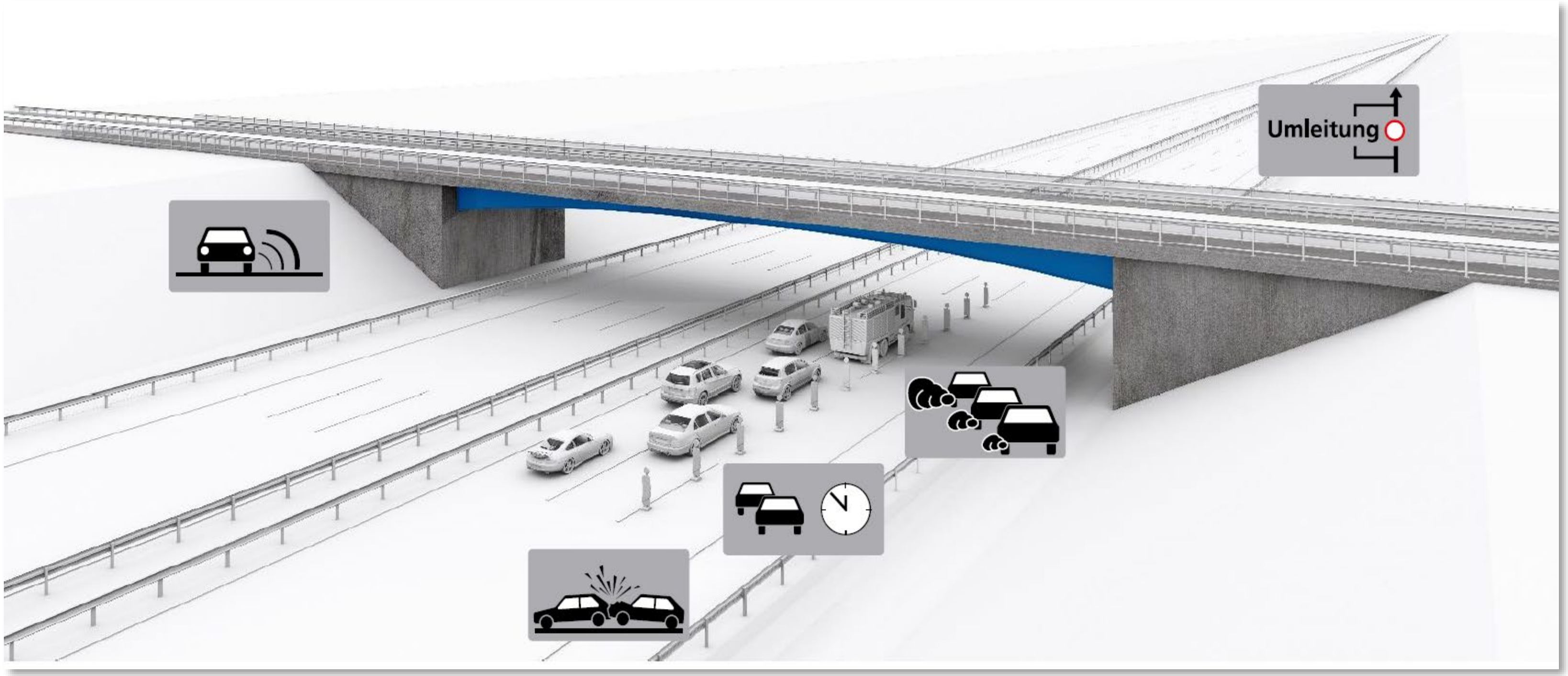
Systainability…

HUESKER
Ideen. Ingenieure. Innovationen.

…but is it only the construction (and demolishion) ?

External effects

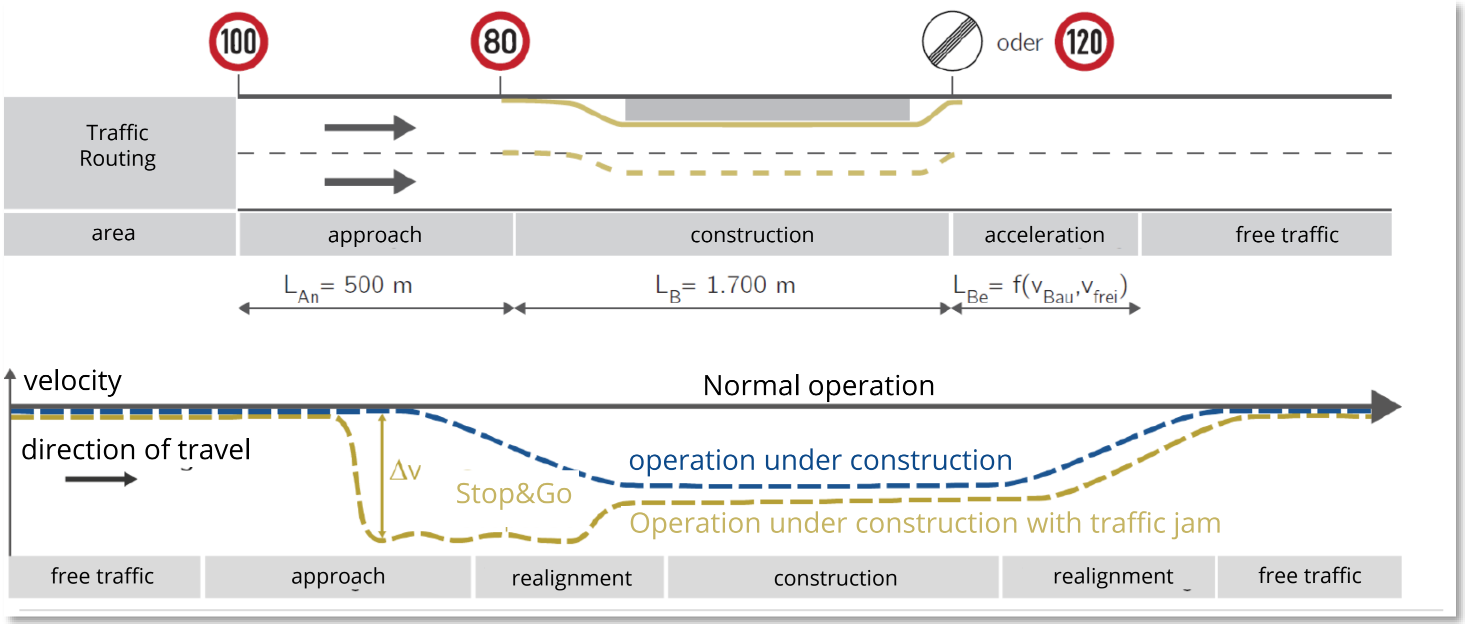
HUESKER
Ideen. Ingenieure. Innovationen.



Reference: Ganzheitliche Betrachtung von Brückenbauwerken, Ergebnisse Forschungsprojekt *NaBrü* , Matthias Müller, Karlsruher Institut für Technologie

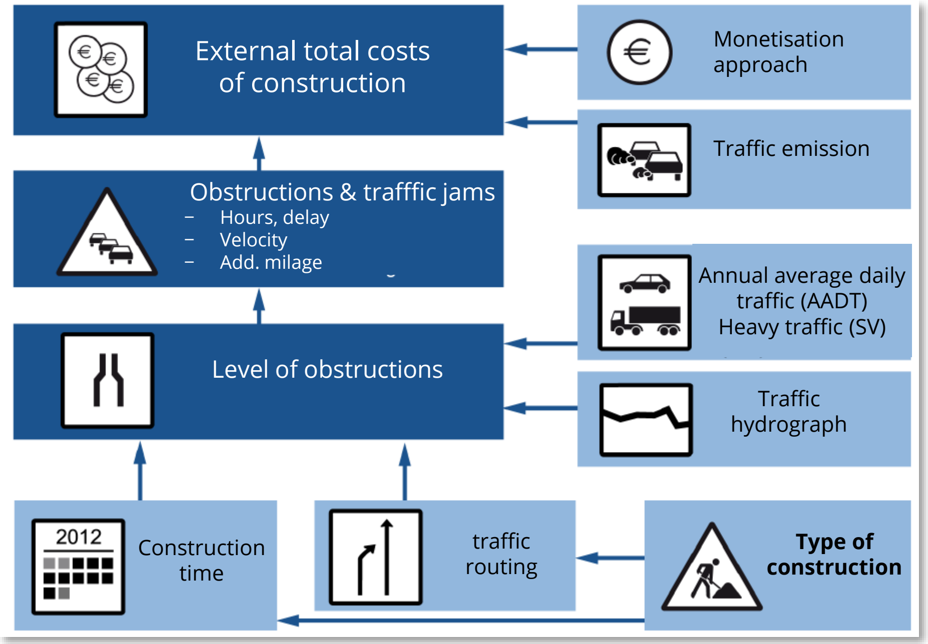
External effects – velocity rate in constructions site

HUESKER
Ideen. Ingenieure. Innovationen.



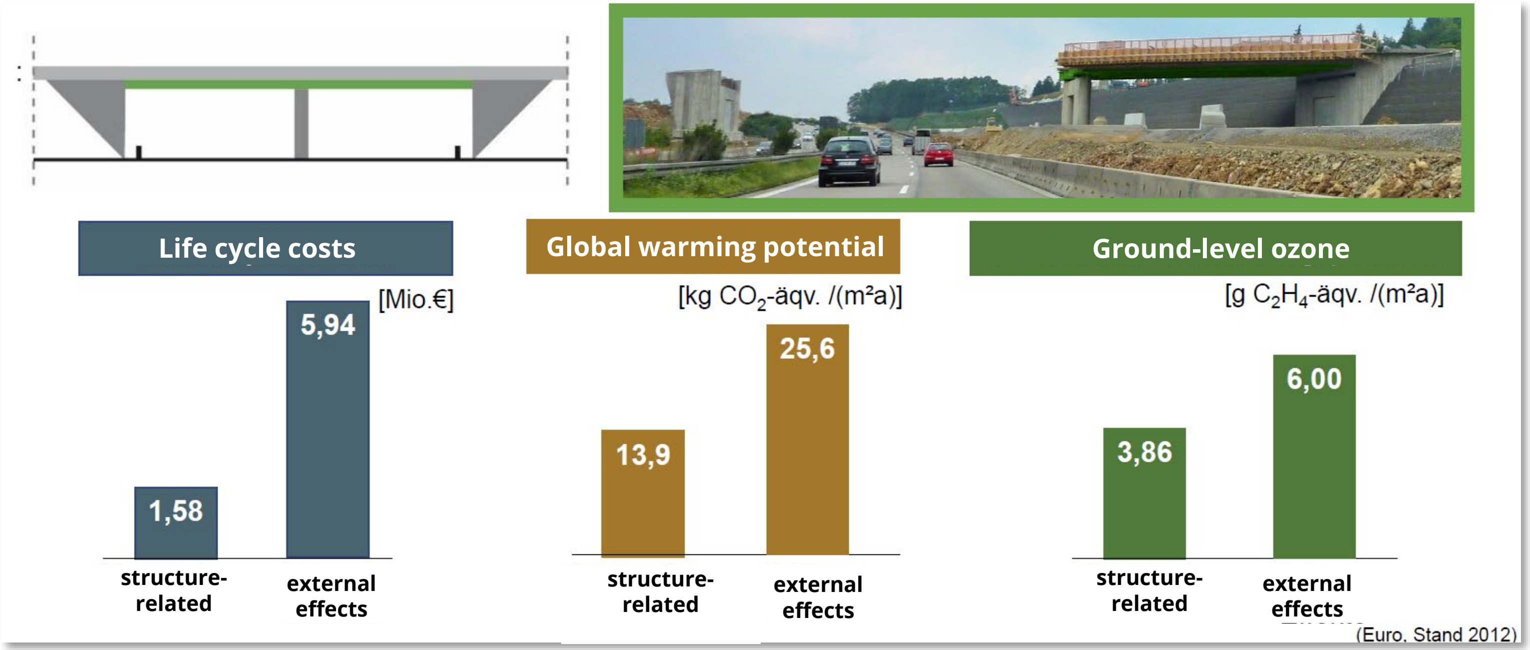
Reference: Ganzheitliche Betrachtung von Brückenbauwerken, Ergebnisse Forschungsprojekt *NaBrü* , Matthias Müller, Karlsruher Institut für Technologie

External effects & total costs



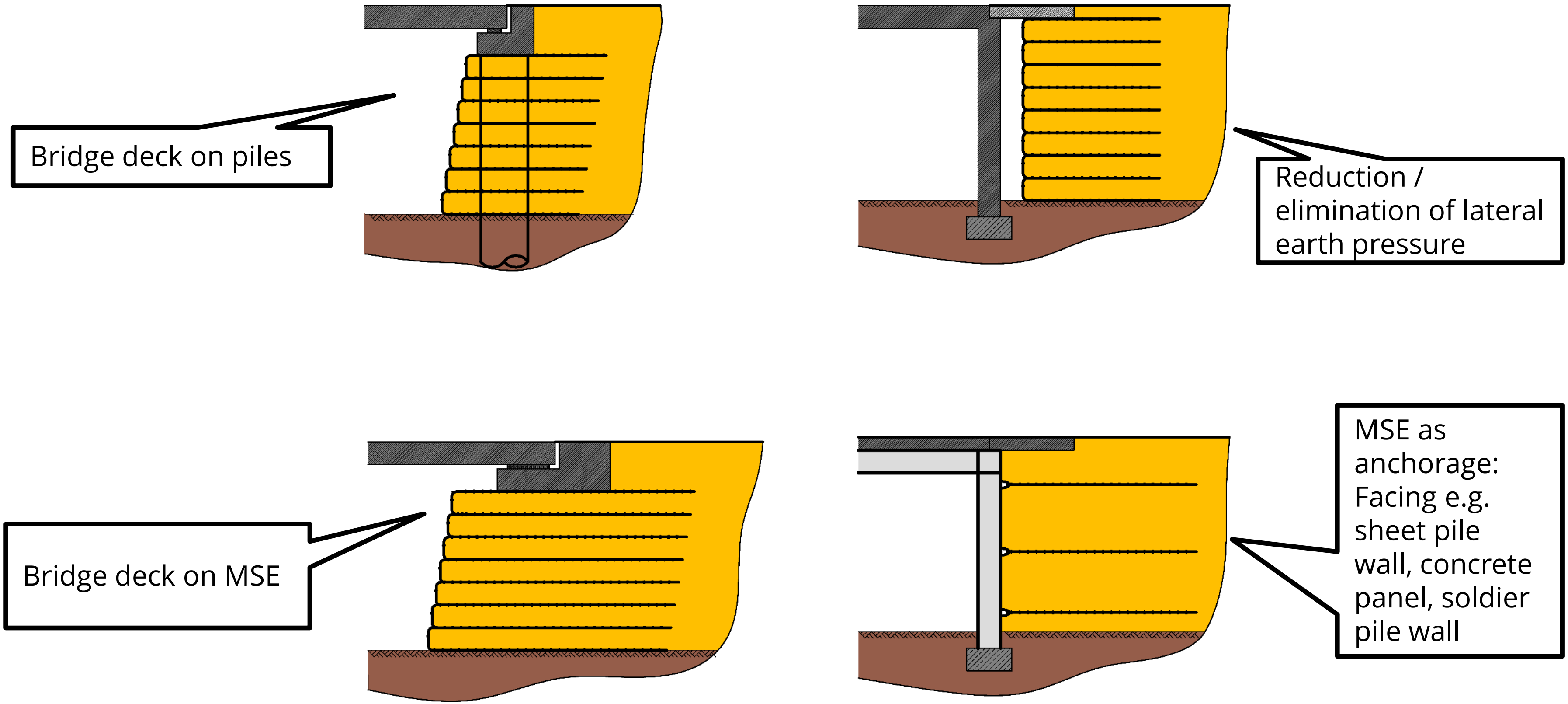
Reference: Ganzheitliche Betrachtung von Brückenbauwerken, Ergebnisse Forschungsprojekt *NaBrü* , Matthias Müller, Karlsruher Institut für Technologie

External effects & total costs



Reference: Ganzheitliche Betrachtung von Brückenbauwerken, Ergebnisse Forschungsprojekt *NaBrü* , Matthias Müller, Karlsruher Institut für Technologie

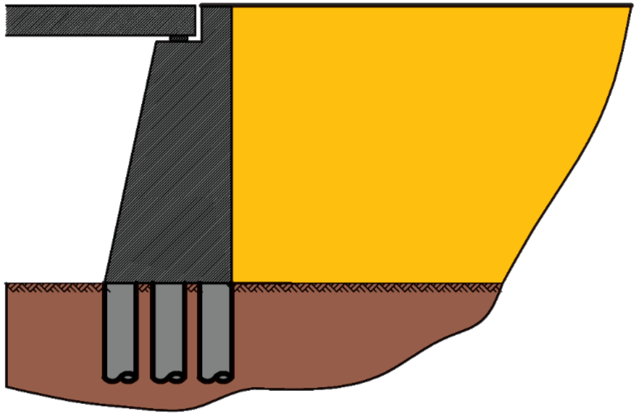
MSE as bridge abutment – various options

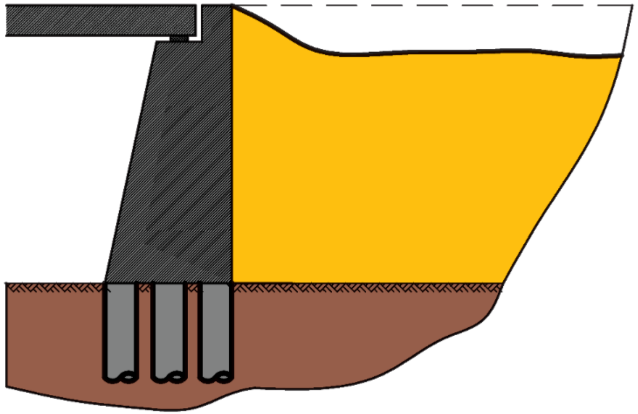


MSE for bridge abutments

HUESKER
Ideen. Ingenieure. Innovationen.

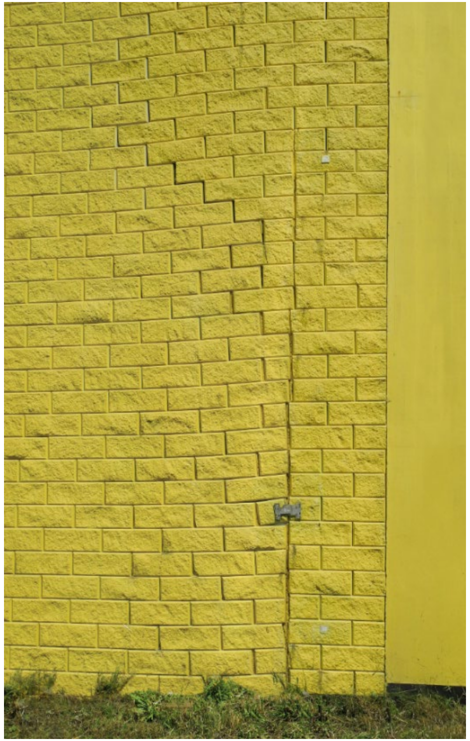
Typical problem with transitions…





Consequences of diff. settlement

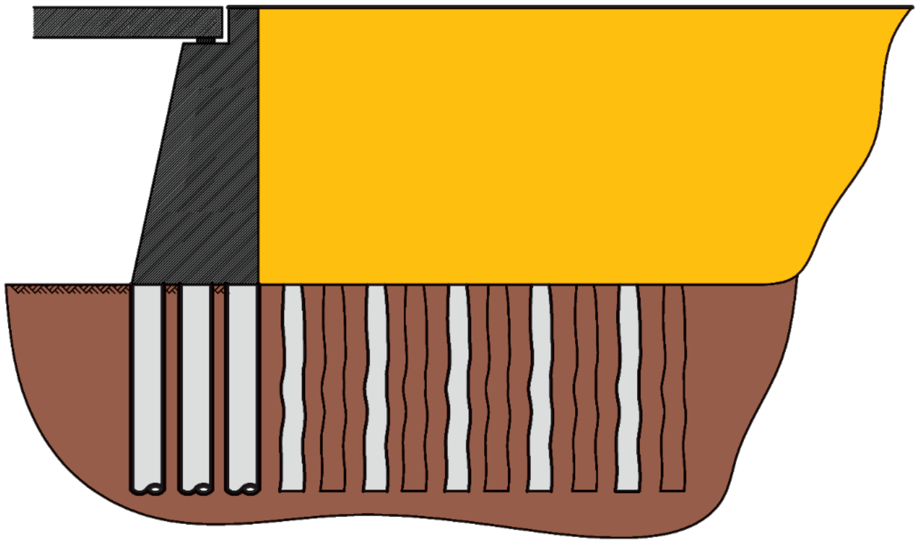
Deformation of a bridge abutment Gdansk (PL)

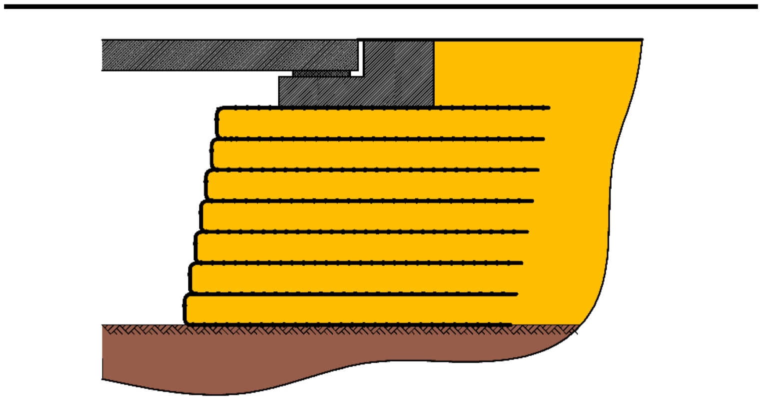


MSE for bridge abutments

HUESKER
Ideen. Ingenieure. Innovationen.

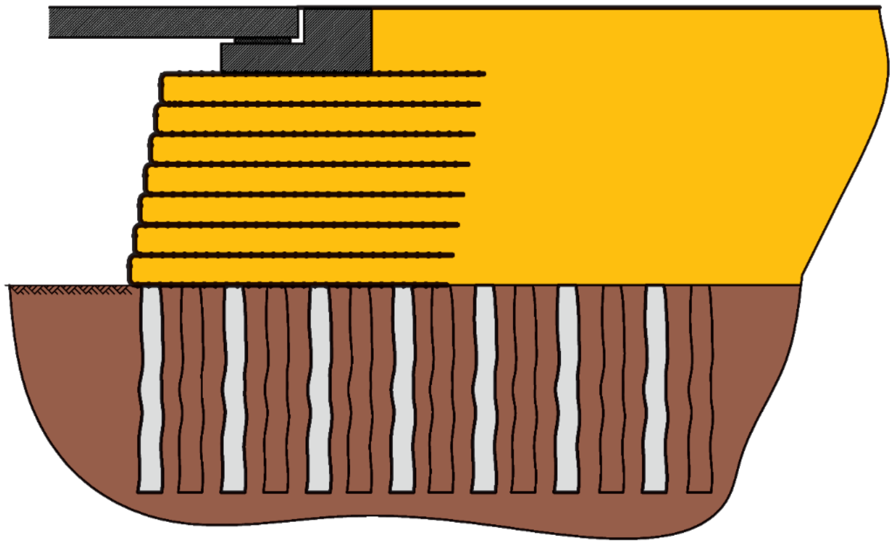
Need for ground improvement or… allow for settlement





MSE for bridge abutments

or… ground improvement vs. piles



…. BUT

- GeoSYNTHETIC –
  is it durable?
- How about deformation…
  at (high and dynamic) loads?

MSE – stability and durability

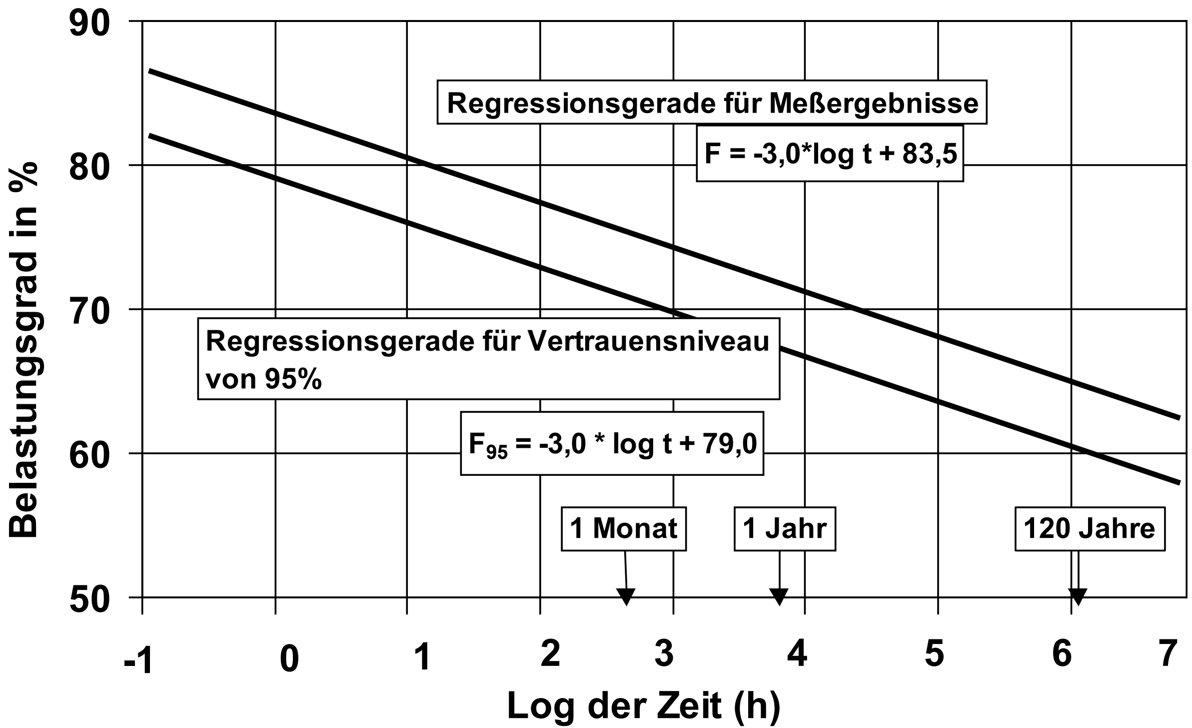
HUESKER
Ideen. Ingenieure. Innovationen.

BUT…

- GeoSYNTHETIC – is it durable?

- …ever

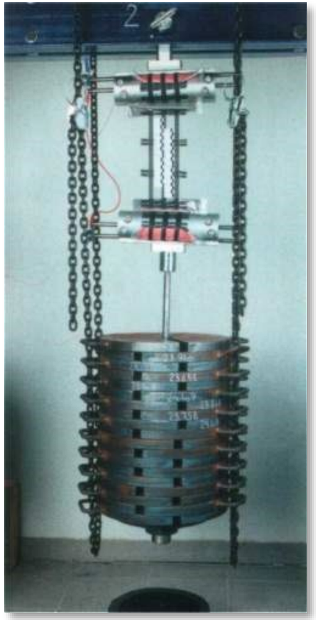
(if used properly)

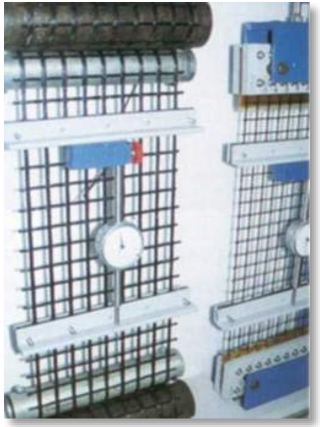


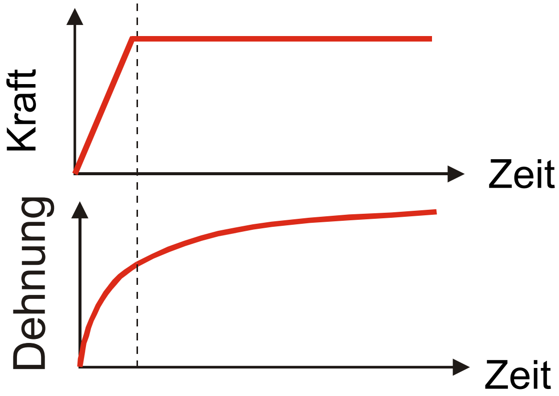
Creep ruptre – curve GG from PVA

Design strength of geogrid

A_1 creep







Ideen. Ingenieure. Innovationen.

…BUT

- How about deformation…
  at (dynamic loads?)

- Possible!

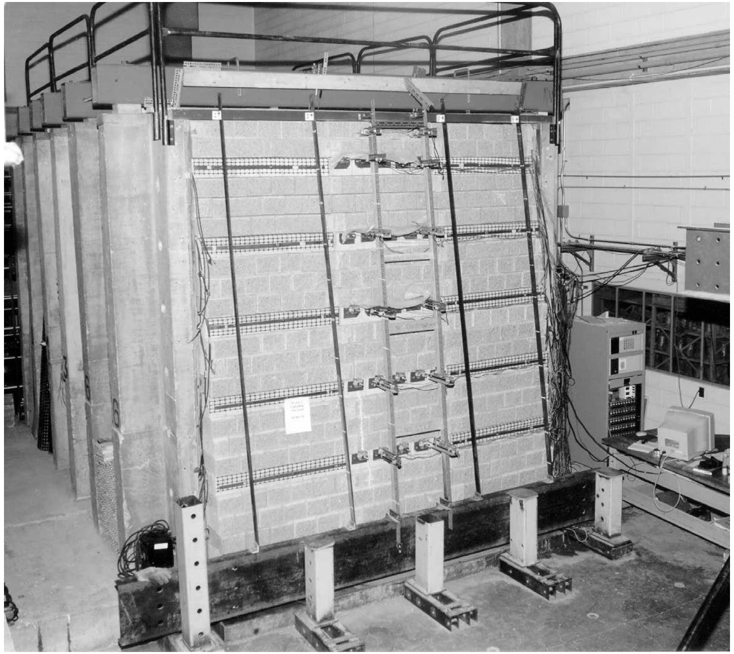
Reail scale test TU München / BAB A8 München / Salzbg. (1997)

- max hor. deformation:
- < 2 mm bei σ = 600 kPa
- < 3 mm bei σ = 800 kPa

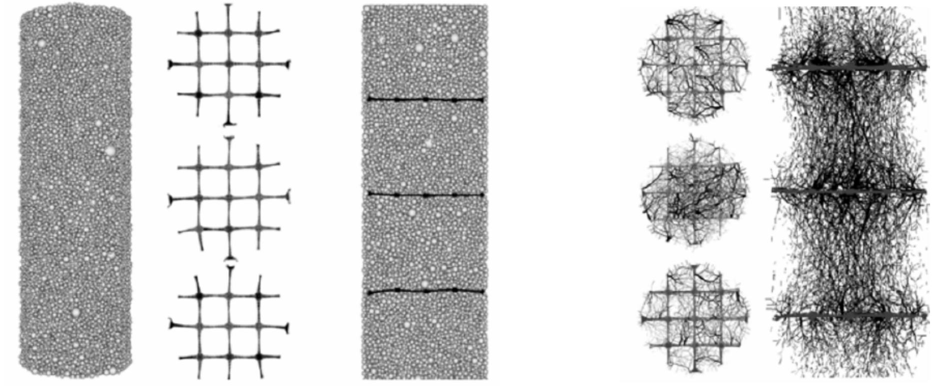
Quelle: Bräu et.al.

MSE-performance testing

Real scale in lab conditions…



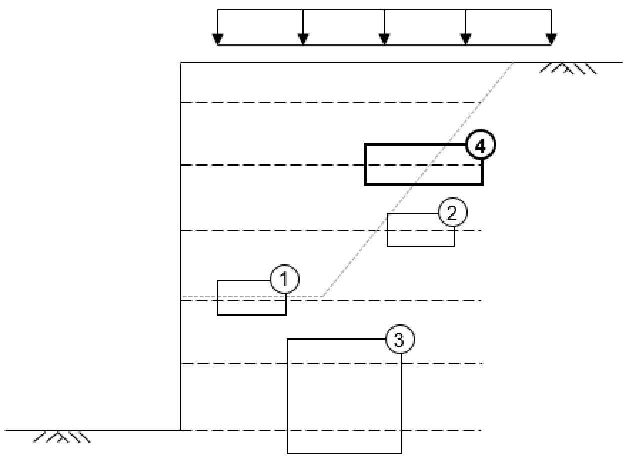
Quelle: Realmaßstäbliche Belastungsversuche
R.J. Bathurst (1999)



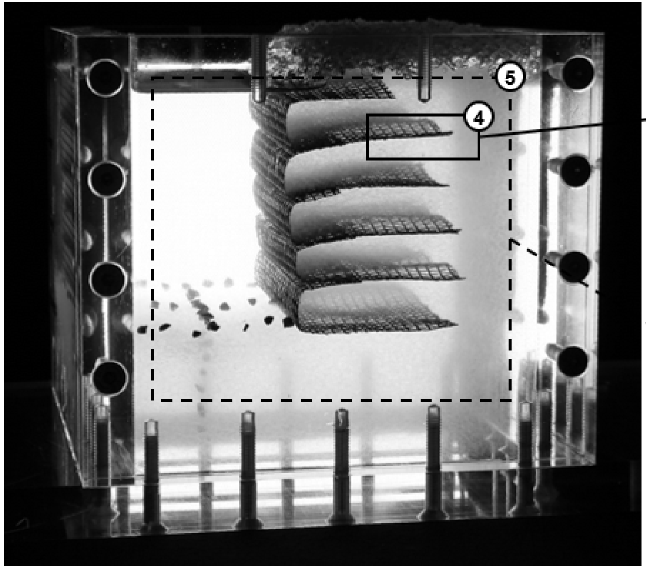
Quelle.: PFC 3D / Konietzky (2006)

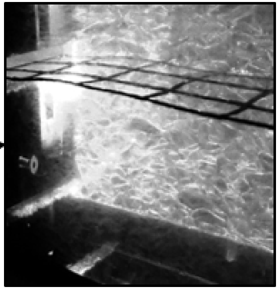
Mikro- und makroskopisches Interaktionsverhalten von geogitterbewehrten Konstruktionen

Untersuchungen zur Boden-Geogitter-Interaktion



1. Kontaktscherversuch
2. Herausziehversuch
3. Bi-/ Triaxiale „Element“-Versuche
4. **Interaktionsversuch**
5. **Klein-/ Großmaßstäbliche Modellversuche**





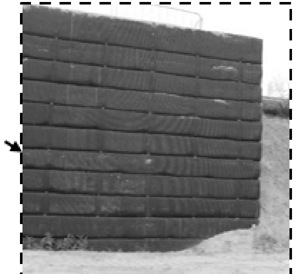
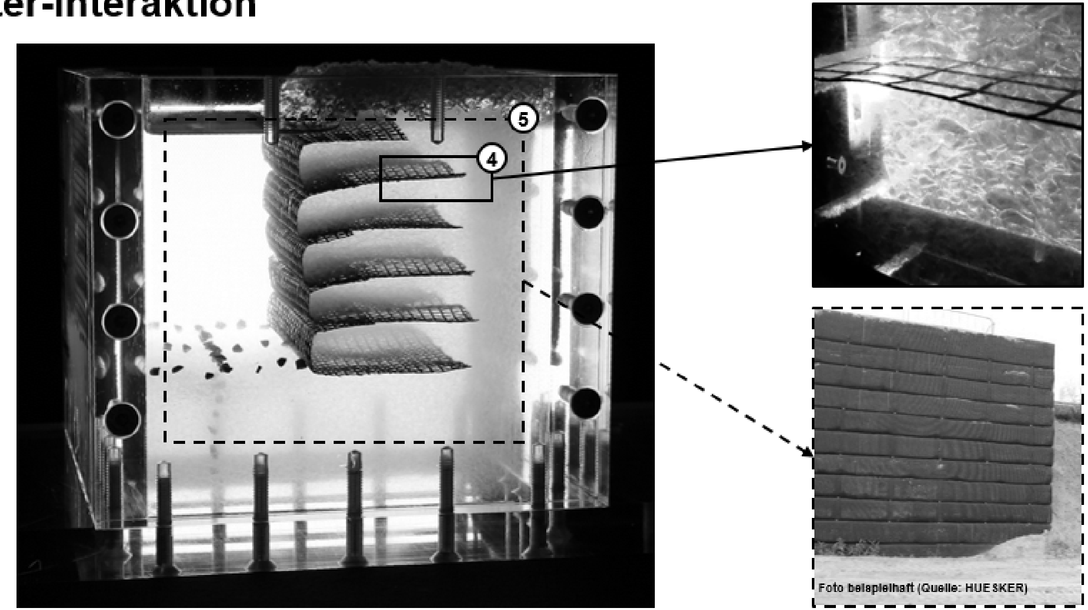


Foto beispielhaft (Quelle: HUESKER)

makro — Beobachtungsebene — mikro

Strukturen	Mechanismen	Effekte	(Unter-)Effekte

Untersuchungen zur Boden-Geogitter-Interaktion



③ Bi-/ Triaxiale „Element"-Versuche

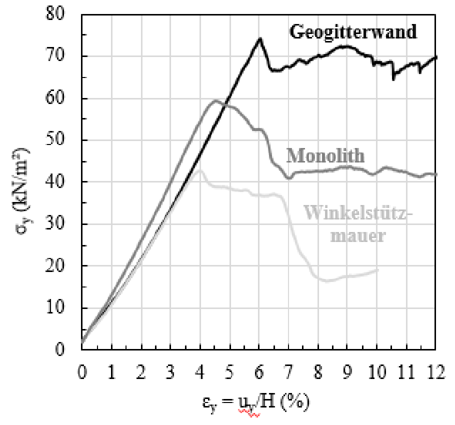
④ Interaktionsversuch

⑤ Klein-/ Großmaßstäbliche Modellversuche

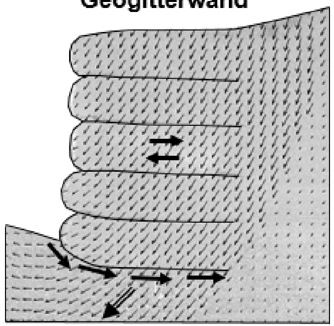
makro — Beobachtungsebene — mikro

Strukturen | **Mechanismen** | **Effekte** | **(Unter-)Effekte**

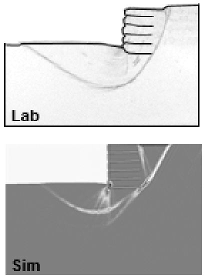
Versagensformen verschiedener Stützkonstruktionen



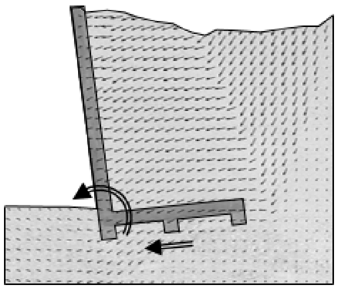
Geogitterwand



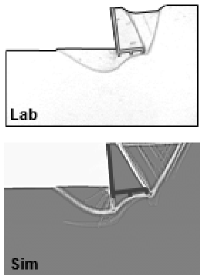
→ Grundbruchversagen



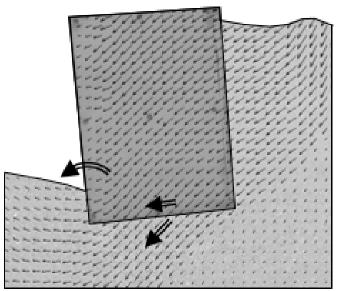
Winkelstützmauer



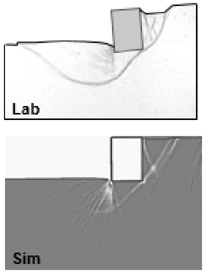
→ Gleiten + Kippen



Monolith

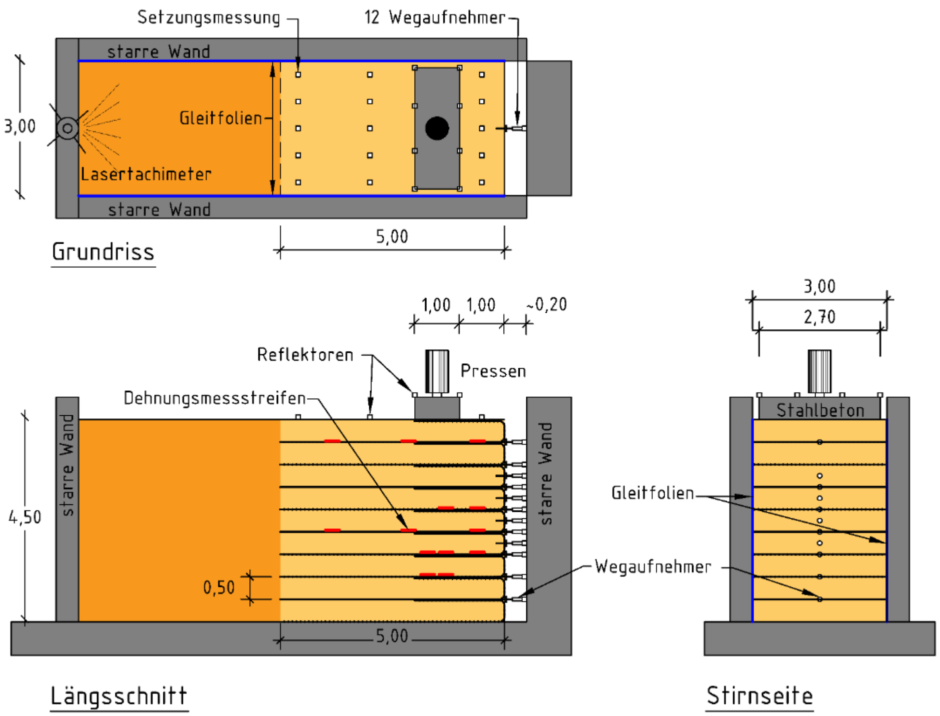


→ Grundbruchversagen
+ Gleiten + Kippen



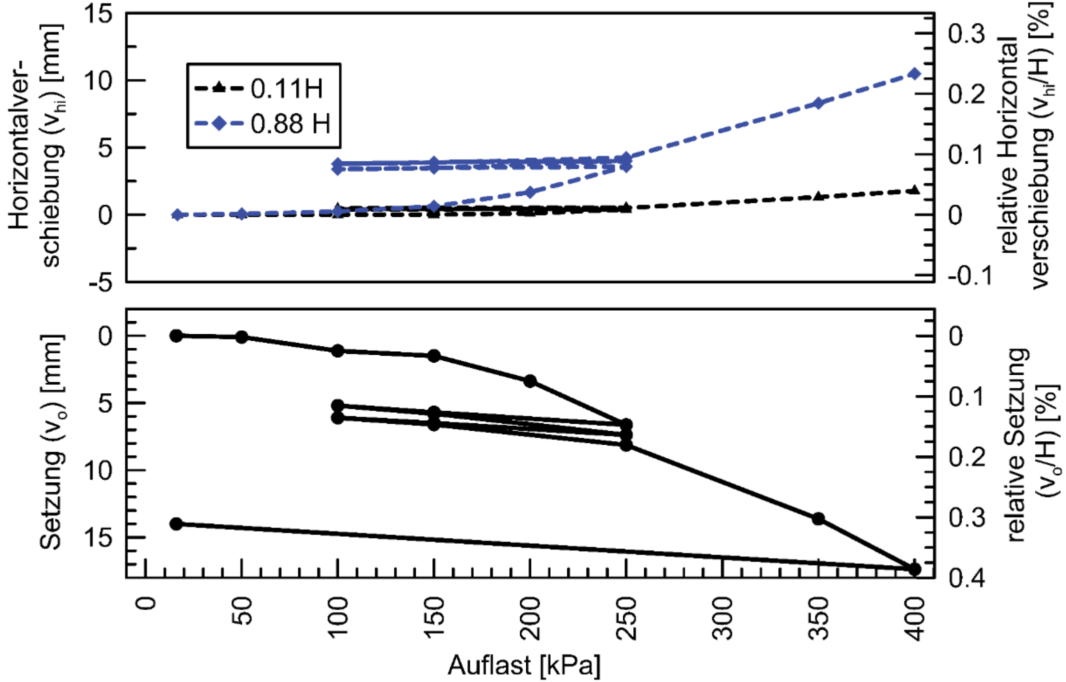
Bearing resistance and deformability

Realscale Test at LGA Nürnberg (2007)



Bearing resistance and deformability

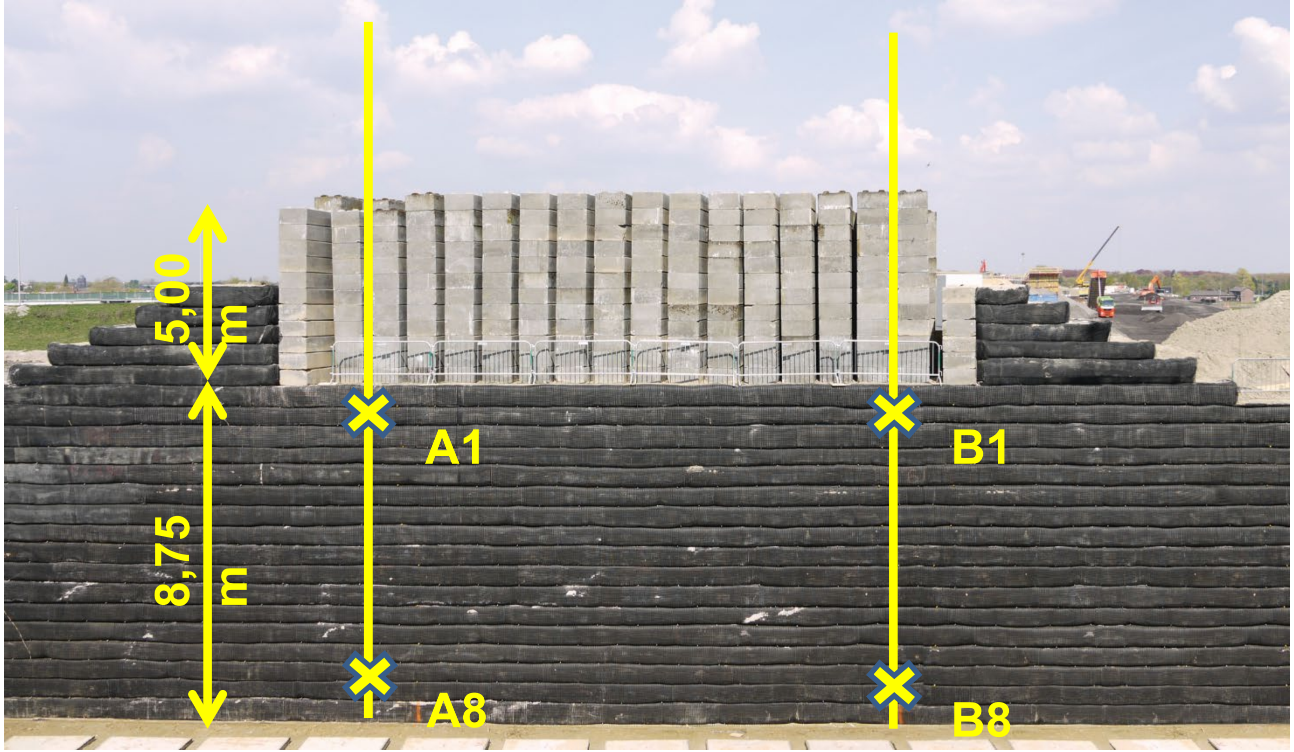
Realscale Test at LGA Nürnberg (2007)



Bem.: max. Auflast ohne Versagen: 600 kPa

Bearing resistance and deformability

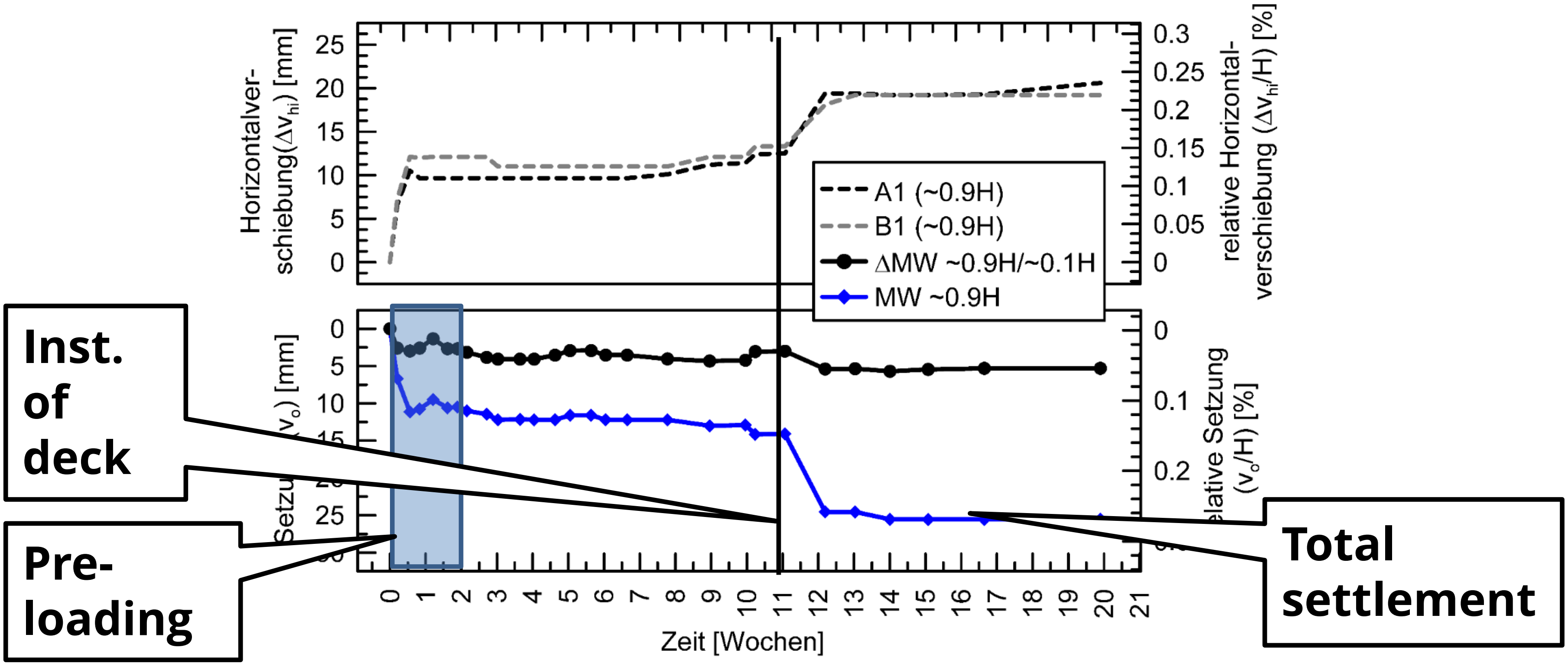
Bridge abutment BAB A74 / Venlo / NL (2011)



Bearing resistance and deformability

HUESKER
Ideen. Ingenieure. Innovationen.

Bridge abutment BAB A74 / Venlo / NL (2011)

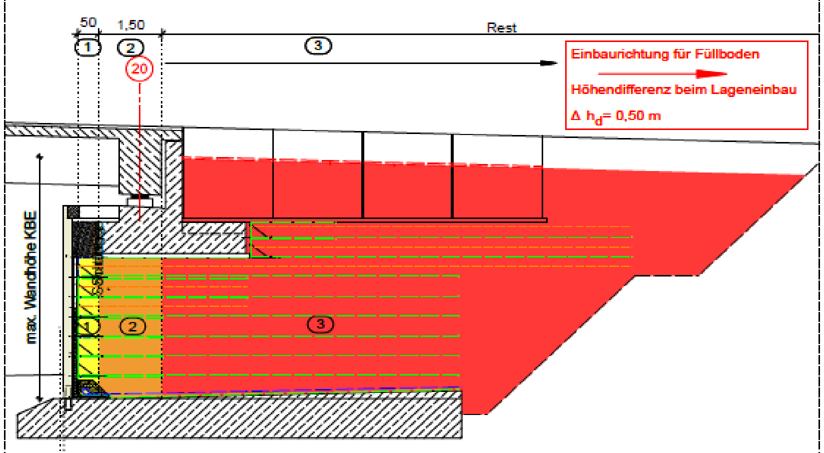


MSE = proper earth works!

HUESKER
Ideen. Ingenieure. Innovationen.

ZULÄSSIGE GERÄTEBELASTUNG

für Verdichtung



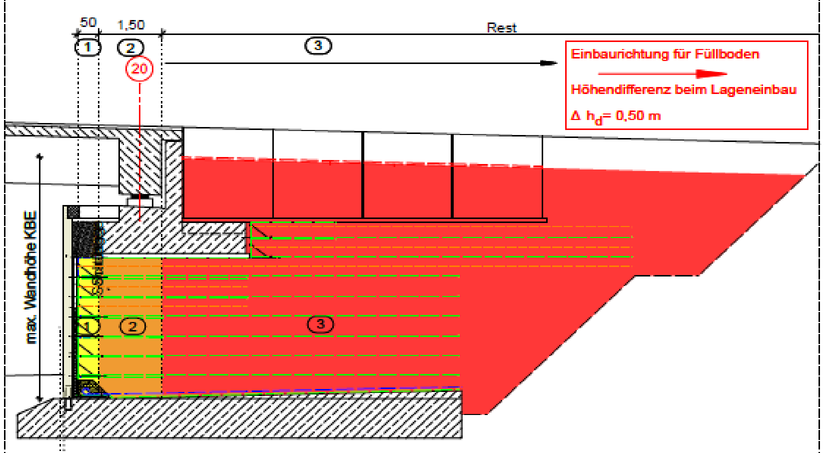
Verdichtung					
Bereich	Beschreibung	zulässige Lasten	Breite	Lagenhöhe	Arbeitsweise
1	Front nur mit Rüttelplatte	G ≤ 0,1 t	b = 0,5 m	d = 0,10...0,15 m	dynamisch
2	Zwischenbereich nur mit Rüttelplatte	G ≤ 0,5 t	b ≥ 1,5 m	d = 0,25 m	dynamisch
3	Hinterfüllbereich Walze, dynamische / statische Betriebsart	G ≤ 12,5 t	ab Bandagen- breite b ≥ 2,0 m	d ≤ 0,50 m	statisch / dynamisch

MSE = proper earth works!

HUESKER
Ideen. Ingenieure. Innovationen.

ZULÄSSIGE GERÄTEBELASTUNG

für Verdichtung



Verdichtung					
Bereich	Beschreibung	zulässige Lasten	Breite	Lagenhöhe	Arbeitsweise
1	Front nur mit Rüttelplatte	G ≤ 0,1 t	b = 0,5 m	d = 0,10...0,15 m	dynamisch
2	Zwischenbereich nur mit Rüttelplatte	G ≤ 0,5 t	b ≥ 1,5 m	d = 0,25 m	dynamisch
3	Hinterfüllbereich Walze, dynamische / statische Betriebsart	G ≤ 12,5 t	ab Bandagen-breite b ≥ 2,0 m	d ≤ 0,50 m	statisch / dynamisch

If something is wrong

Analysis of 171 failures

- Type of failure SLS/ULS 74% ULS / 26 % SLS
- **Compaction 72% bad**

- Qualität of fill 61% cohesive soils
- drainage 60% bad drainage

- Bad / NO design 98%
- private / administration 96% privat

- **Reason for failure was NOT the Geosynthetic**

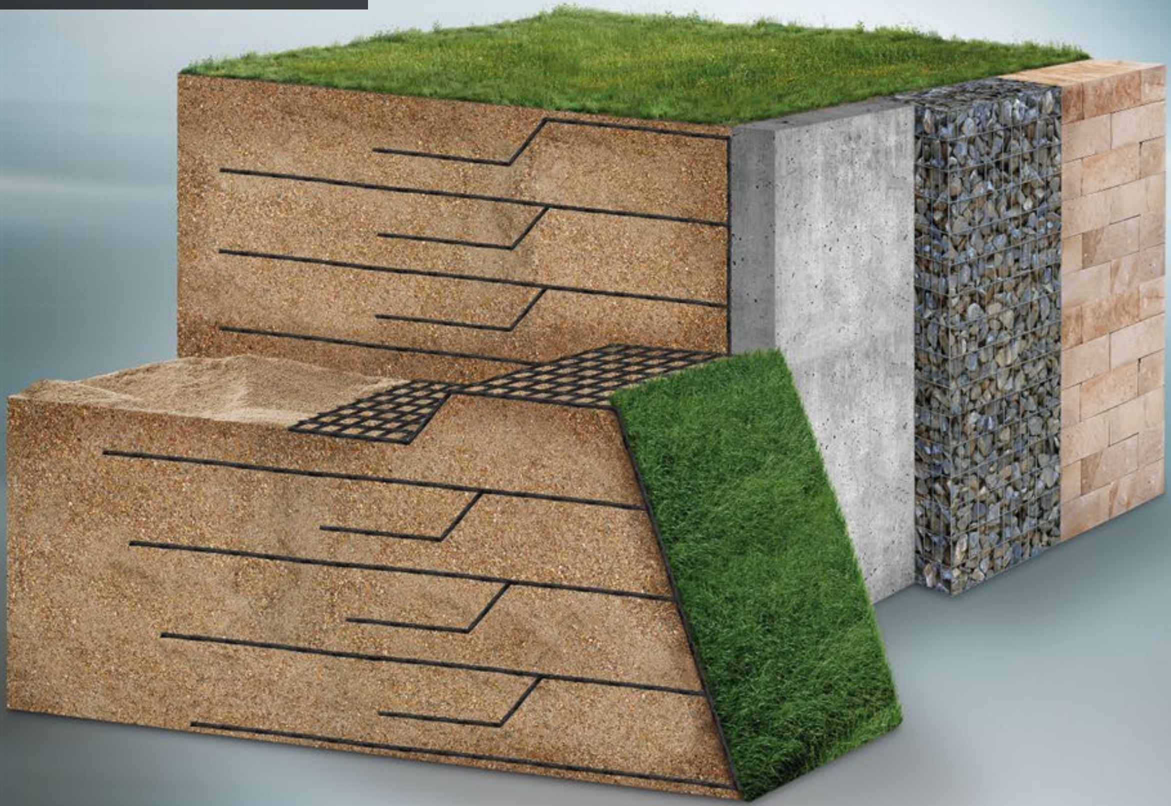
Do it yourself…

Conclusion

- Proven technology … even for
  - steep (vertical) structures and
  - high loading

- Sustainability technology with regard to
  - Construction
  - Materials / Technology
  - Maintenace
  - „differential settlement“

Thank You!



Discover Fortrac Systems
now also in the
Augmented Reality App

Questions


How
When
Where
How
Why
Where
When
Why
Who
Who
When
What
What
What
When
How
When
Who
Where
Why
How