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„Magic Effects" on geogrid-reinforced soil explained by triaxial testing at low strains

TC-Reinforcement Workshop:
Research on Geosynthetic-Soil Interaction and Progress of Design Models for Geosynthetic-Reinforced Soil

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Ulrike Weisemann — HTW Dresden, Germany
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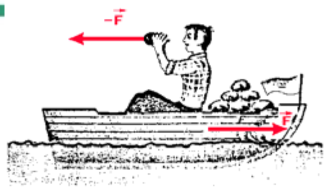
Arnstein Watn — SINTEF, Norway

Shortcut

… just mechanical law.

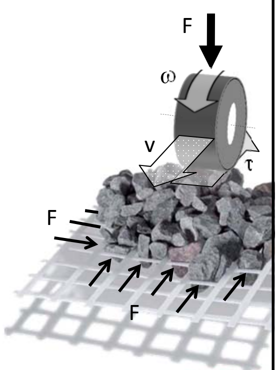
$\vec{F}_{A\to B} = -\vec{F}_{B\to A}$

(Third law of Sir Isaac Newton, 1697)



„actio equal reactio"

or



Transferred to soil reinforcement:

" The grains have to be kept in place".

Prof. Dr.-Ing. Georg Heerten, 2004

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Reinforcement, separation and filtration of unbound granular layers ...

 NorGeoSpec SINTEF 5 BAUBERATUNG GEOKUNSTSTOFFE

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... reinforcing and stabilizing superstructures for improved serviceability.

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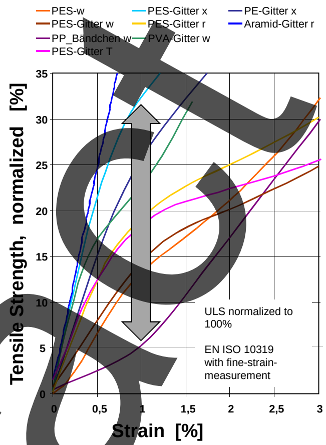
Accepted applications

Constructions on weak subsoil:

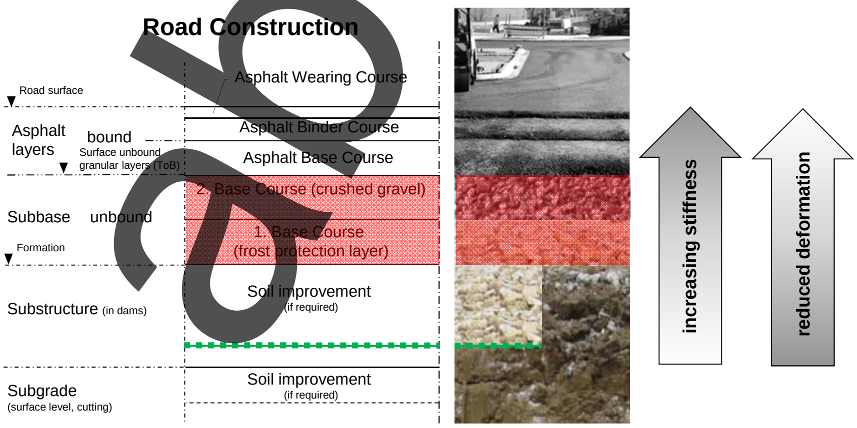
Temporary Roads

Making use of Membrane-Modell with more or less empirical modifications (Giroud-Noiray, Giroud-Han, etc.), the reinforcement shows significant deformation.

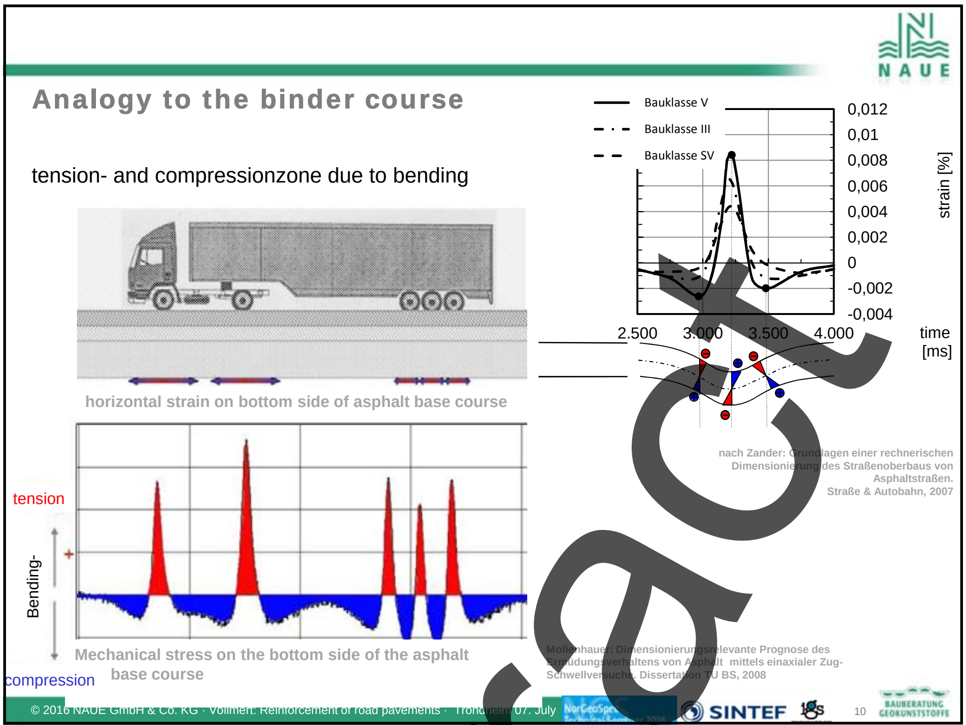
Müller-Rochholz, J. (1999): Verformungsverhalten von geosynthetischen Bewehrungen im Gebrauchslastbereich



Motive



Secugrid® – Researchforum of NAUE GmbH & Co. KG. Forsthaus Limberg, 2004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Analogy to the binder course
tension- and compressionzone due to bending
horizontal strain on bottom side of asphalt base course
tension
Bending-
compression
Mechanical stress on the bottom side of the asphalt base course
Bauklasse V
Bauklasse III
Bauklasse SV
0,012
0,01
0,008
0,006
0,004
0,002
0
-0,002
-0,004
strain [%]
2.500
3.000
3.500
4.000
time [ms]
nach Zander: Grundlagen einer rechnerischen Dimensionierung des Straßenoberbaus von Asphaltstraßen. Straße & Autobahn, 2007
Mollenhauer: Dimensionierungsrelevante Prognose des Ermüdungsverhaltens von Asphalt mittels einaxialer Zug-Schwellversuche. Dissertation TU BS, 2008
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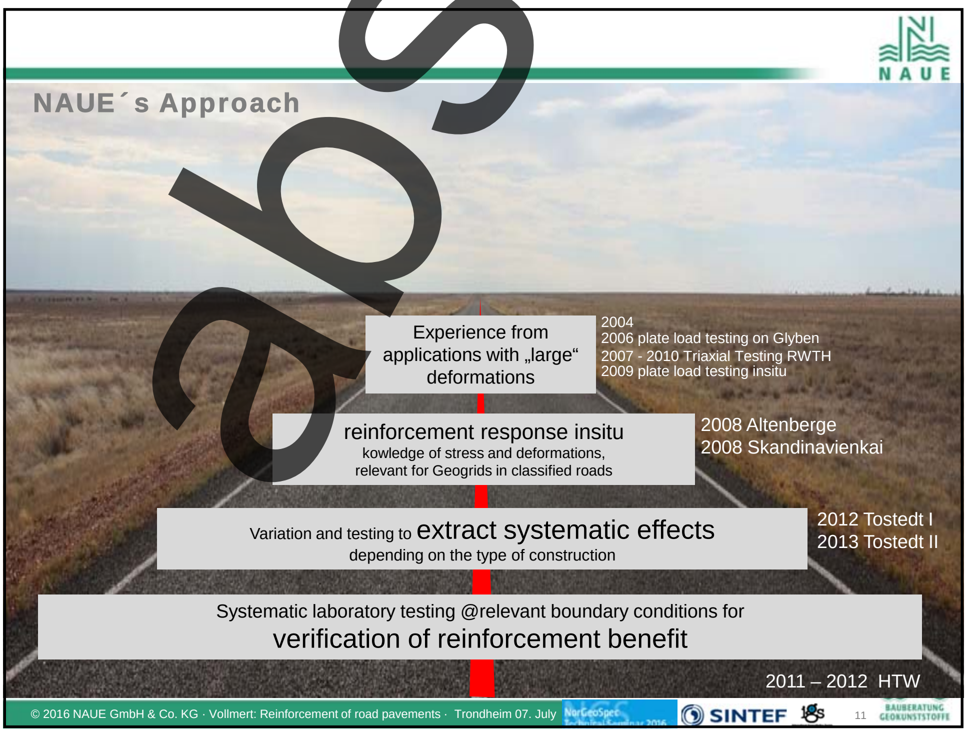
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NAUE´s Approach
Experience from applications with „large“ deformations
2004
2006 plate load testing on Glyben
2007 - 2010 Triaxial Testing RWTH
2009 plate load testing insitu
reinforcement response insitu
kowledge of stress and deformations, relevant for Geogrids in classified roads
2008 Altenberge
2008 Skandinavienkai
Variation and testing to extract systematic effects depending on the type of construction
2012 Tostedt I
2013 Tostedt II
Systematic laboratory testing @relevant boundary conditions for verification of reinforcement benefit
2011 – 2012 HTW
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Reinforcement response insitu
NAUE
Reference projects
for basic information on reinforcement response insitu
NAUE
www.naue.com
Lübeck, Skandinavienkai
OU Altenberge, K50n
Kiel
Rostock
Hamburg
Schwerin
Bremen
Berlin
Hannover
Osnabrück
Magdeburg
Bielefeld
Cottbus
Dortmund
Kassel
Leipzig
Köln
Bonn
Erfurt
Dresden
Frankfurt am Main
Würzburg
Mannheim
Nürnberg
Saarbrücken
Karlsruhe
Stuttgart
Passau
Ulm
München
Freiburg
Soil class I/II following RStO 01
3,5 cm grit mastic
8,5 cm asphalt binder
14 cm asphalt base course
40 cm HKS base course
welded PET geogrid
30 cm Ibbenbürener sandstone 0/100
welded PET geogrid
10 cm Ibbenbürener sandstone 0/100
STS
welded PP-geogrid
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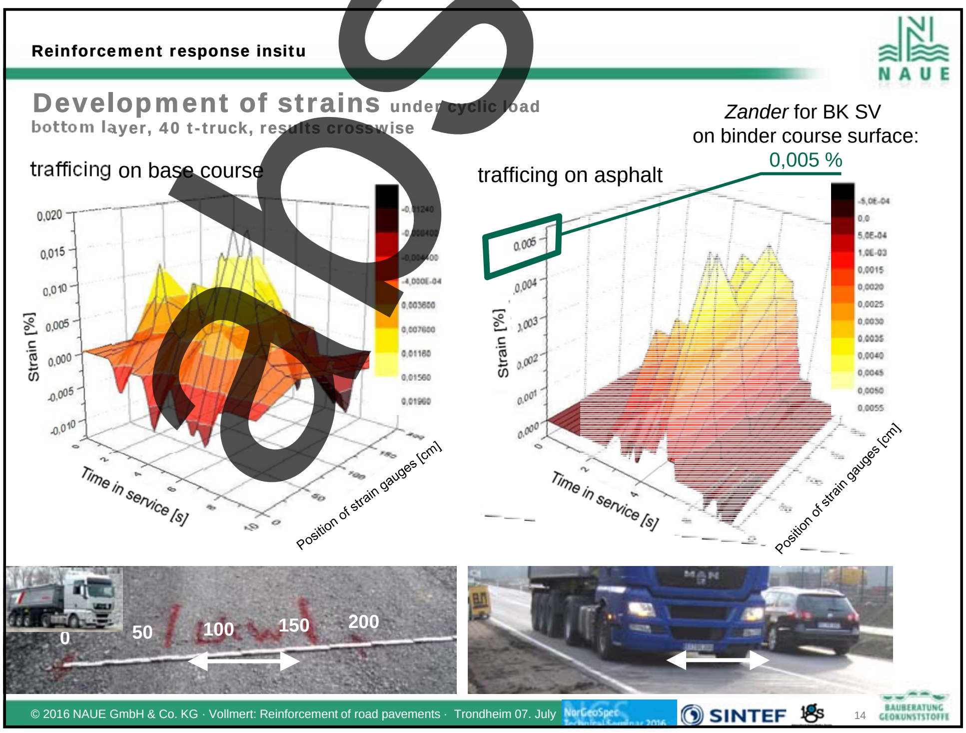
Reinforcement response insitu
NAUE
Development of strains under cyclic load
bottom layer, 40 t-truck, results crosswise
trafficing on base course
trafficing on asphalt
Zander for BK SV
on binder course surface:
0,005 %
Strain [%]
Time in service [s]
Position of strain gauges [cm]
0
50
100
150
200
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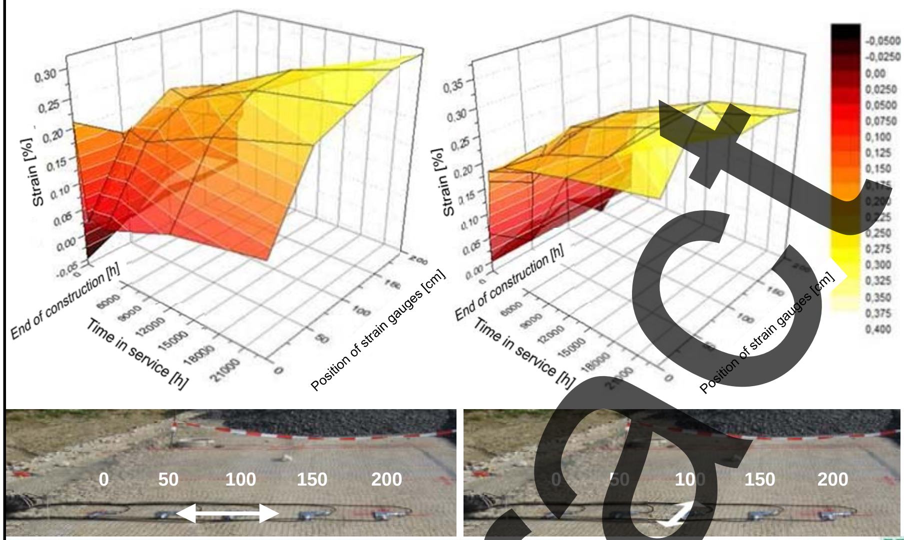
Reinforcement response insitu

Development of strains accumulated plastic strain bottom layer

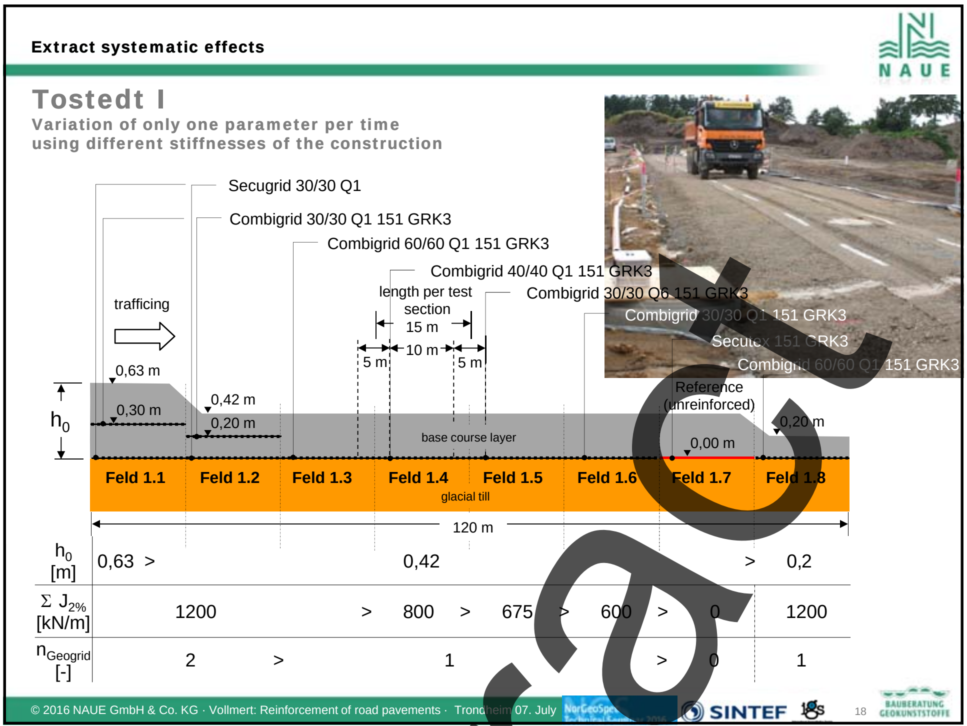


Extract systematic effects

Testsites since 2004 Montana I & II (USA), Tostedt I & II (D)

	Montana I	Montana II	Tostedt I	Tostedt II
	2009	2014	2012	2015
Task				
Product-Comparison	X	X		X
BCR / LCR-values	X	X	X	X
Validation of design-concepts		X	X	
Conception				
Testsections	12	17	8	8
Length [m]	15	17,4	15	15
Axle load 1 / 2 / 3 [t] Total load [t] / N_{10t}/pass	5,3 / 7,8 / 7,7 20,9 / 0,88	5,0 / 7,9 / 7,7 20,6 / 0,88	7,8 / 10,1 / 10 27,9 / 2,41	7,8 / 10,4 / 10,3 28,5 / 2,66
Filterstability Formation vs. Substructure (hydrodynamic)	X			
Separation / Filtration Function given for all Products		[1]	X	X
Different Product – Groups	X	X	only Secugrid/ Combigrid	X
Δ Number of reinforcement layers n			X	
Δ Stiffness at constant product structure			X	
Δ Construction height		X	X	X
Reduced variability			X	
CBR of subsoil/formation[2] [%]	1,80	1,64[3] 1,79 2,17[3]	2,06	1,33
Construction height h_0 [m]	0,2	0,28 0,41[4] 0,63[4]	0,2 0,4 0,65	0,5 0,65

[1] Only given for two sections using woven and nonwoven products
[2] Mean of all test sections
[3] Reinforced sections with the same product
[4] Control sections


Extract systematic effects
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Tostedt I
Variation of only one parameter per time
using different stiffnesses of the construction
Secugrid 30/30 Q1
Combigrid 30/30 Q1 151 GRK3
Combigrid 60/60 Q1 151 GRK3
Combigrid 40/40 Q1 151 GRK3
Combigrid 30/30 Q6 151 GRK3
Combigrid 30/30 Q1 151 GRK3
Secutex 151 GRK3
Combigrid 60/60 Q1 151 GRK3
trafficing
length per test section
15 m
10 m
5 m
5 m
0,63 m
0,30 m
0,42 m
0,20 m
base course layer
Reference (unreinforced)
0,00 m
0,20 m
Feld 1.1
Feld 1.2
Feld 1.3
Feld 1.4
Feld 1.5
Feld 1.6
Feld 1.7
Feld 1.8
glacial till
120 m
h_0 [m]: 0,63 > 0,42 > 0,2
$\Sigma J_{2\%}$ [kN/m]: 1200 > 800 > 675 > 600 > 0 1200
$n_{Geogrid}$ [-]: 2 > 1 > 0 1
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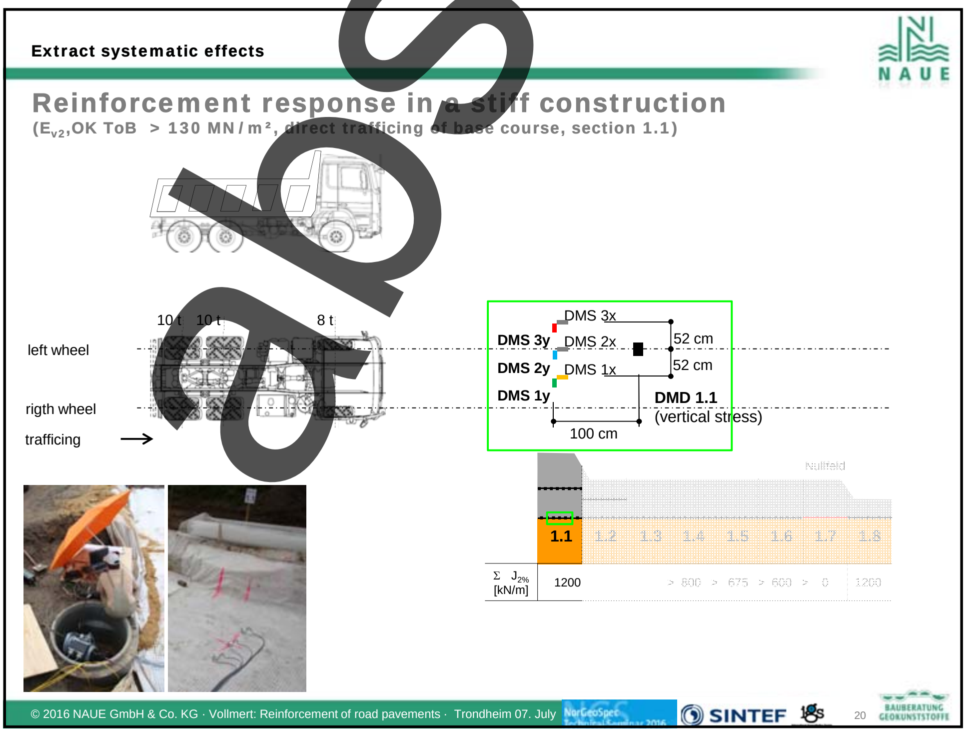
Extract systematic effects
NAUE
Reinforcement response in a stiff construction
(E_{v2},OK ToB > 130 MN / m², direct trafficing of base course, section 1.1)
10 t
10 t
8 t
left wheel
rigth wheel
trafficing
DMS 3x
DMS 2x
DMS 1x
DMS 3y
DMS 2y
DMS 1y
52 cm
52 cm
DMD 1.1
(vertical stress)
100 cm
Nullfeld
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
$\Sigma J_{2\%}$ [kN/m]
1200
> 800 > 675 > 600 > 0
1200
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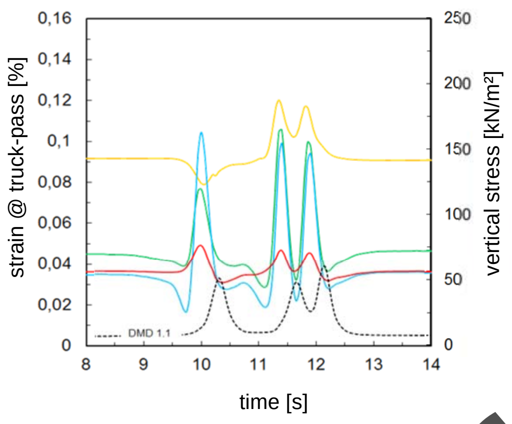
BAUBERATUNG GEOKUNSTSTOFFE

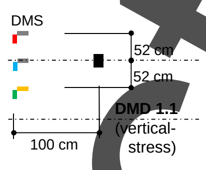
Extract systematic effects

Reinforcement response in a stiff construction

(E_{v2},OK ToB > 130 MN/m², direct trafficing of base course, section 1.1)

Exemplarily:





Extract systematic effects

Mechanical response of a reinforcement layer to trafficking

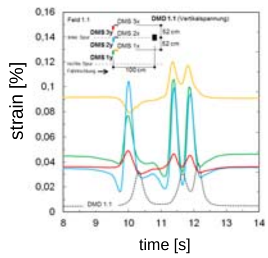
Comparing different types of construction

(unpaved vs. paved constructions, very weak constructions vs. very stiff constructions)

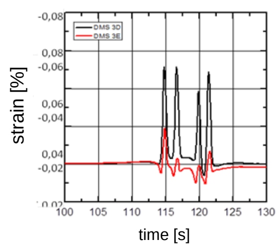
we find **always the same mechanical response of the geogrid to a truck pass**,

with a compression phase first and tensile strains while passing.

Just the magnitude of stress-strain-condition differs.



Example for ***unpaved*** construction



Example for ***paved*** construction

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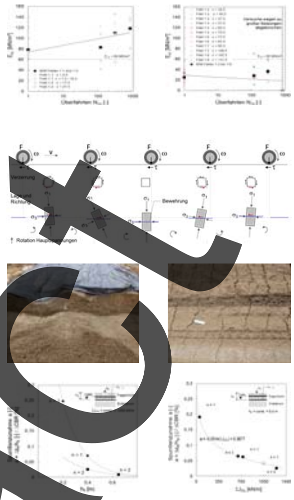
Some main conclusions

- A certain stiffness of the overall construction has to be ensured for proper long-term-performance ($E_{v2} \geq 60$ MN/m²) on weak subsoils in case of direct trafficking.
- Significant lateral shear stress is induced to the reinforcement by rotating principal stress and lateral driving forces.
- The total construction is deformed in different directions, crosswise as also in longitudinal direction.
- The strength-strain characteristic of the reinforcement (e.g. stiffness J [kN/m] at small deformation) as design value as well as the distribution of the stiffness within the construction is of most important influence for the performance of the construction:
  Constructions with distributed stiffness (two layers @ bottom and middle of the construction) outperform constructions concentrating the same sum of stiffness in only one layer @ bottom)



Vollmert, 2016

Extract systematic effects

NAUE

Some main conclusions

Significat and unexpected result:

4-power-law **not** satisfactory for unpaved roads neither for unreinforced, nor for reinforced conditions

4-power-law based on AASHTO-raod test

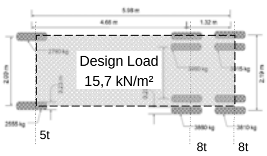
$$N_{10t} = \left(\frac{L_i}{L_{10t}}\right)^{4 \;(5 \ldots 8)}$$

N_{10t} equivalent 10 t axle passes
L_{10t} normative axle load 10 t
L_i axle load

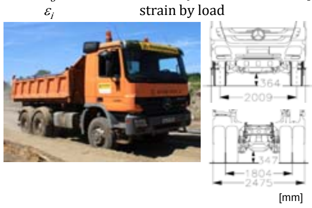
fatique model (Yoder & Witczak, 1975)

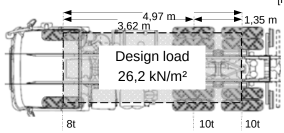
$$F_j = \left(\frac{\varepsilon_i}{\varepsilon_{8t}}\right)^{4 \;(5 \ldots 8)}$$

F_j equivalent fatique factor
ε_8 strain by 8t-standard axle pass
ε_i strain by load



typical test conditions US and elder UK trials





typical trafficking conditions EU

Extract systematic effects

NAUE

Some main conclusions

- A stiff product structure providing interaction with the grain structure is essential and can be provided by rigid and welded bars. Radial stiffness as well as apperture stability modulus can be used for characterisation of product stiffness, added to the requirements of harmonised standards.

- Neither systematic test on triaxial test-apparatus, nor site trafficking tests did show a better performance of multiaxial product structures compared to biaxial product structures. In constructions with pronounced deformations the ultimate tensile design strength becomes important as additional factor to provide the required robustness of the construction.

- At weak subsoil conditions, missing separation (leading to fine grain contamination) can superimpose reinforcing effects.
  Therefor, direct comparison of test results of grids *without* separator and wovens are missleading (due to underestimating grid performance).

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Reinforcement benefit – element testing RWTH Aachen

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Interaction of grain structure, stiffness and product structure

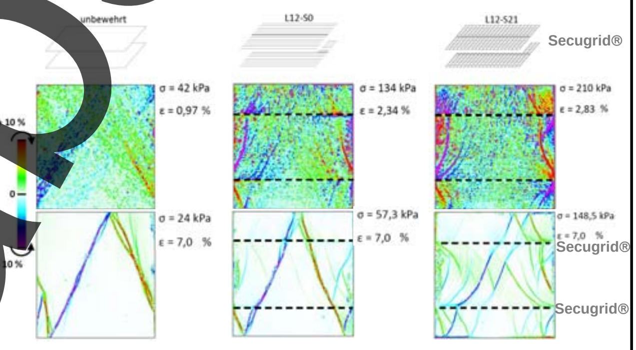
Element test by Ziegler, Ruiken & Jacobs (RWTH Aachen) show, that

- if discrete shear planes are developed, the deformations are concentrating on these zones

- the reinforcement retards the development of discrete shear planes (dependend on stiffness-characteristics and distribution of crossbars)

- shear planes are more distributed by cross-bars

- the shear-zones are doweled by the stiffness of the longitudinal bars.



Comparison of shear planes @ ε_1 = 7,0 % (Jacobs, 2015b)

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Reinforcement benefit - Triaxial testing with cyclic loads

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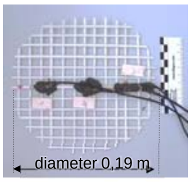
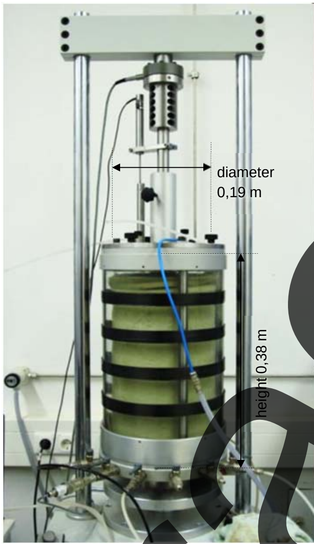
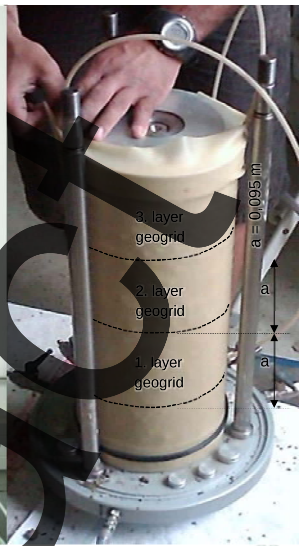
Scaled tests at HTW Dresden

- geogrid Secugrid 30/30 Q1, geometrically scaled to 1 : 2,6
- CU and CD-tests according ASTM D 3999-91 DIN 13286-7
- finally decided for tests with realistic stress history for both samples: DIN 13286-7 modified: 2 Hz, σ_3=45 MPa, increase of deviatoric stresses @ 10000 load cycles







Summary

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Interim conclusions:

In the service load range of paved or unpaved roads, the unbound granular layers are subject to strains, which

- remain small, but which will become relevant by the number of load cycles N due to accumulated plastic strains.

The mechanical response of the construction and qualitative development of these strains can be seen as to be **always the same, but different in magnitude** depending of the stiffness of the overall construction.

- The reinforced base course reduces the bending- and tensile-stresses of the base course effectively by **applying a local restraining** force and stabilizing the grain structure of the unbound granular layers. The (deformed) reinforcement induces a **permant lateral stress state** to the grain structure (confinement).
- The **distributed stiffness** (e.g. double-layer) reinforcement (e.g. at the Skandinavienkai) reacts more efficiently.

Thus, although the elastic parameter are mainly influenced by the granular material itself, the **critical accumulated plastic strains can be reduced efficiently by distributed strengthening of the granular materials by geogrids** even in very stiff conditions.

Assuming that membrane action is required to gain positive effects, is obsolet for geogrids with stiff product structure and high tensile stiffness.