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Installation damage of geosynthetics and consequences for the design

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Outline

- Introduction
- Installation damage
  - Concept, how to avoid / minimise, mechanisms
- Main consequences of installation damage
  - Visual changes, mechanical response
- Some results and consequences for design
- Recommendations and summary

Part 1

INTRODUCTION

Durability

Endurance

- Installation damage
- Creep & creep rupture
- Stress relaxation
- Abrasion
- Compressive creep

Degradation

- Oxidation
- UV radiation
- Hydrolysis
- Chemical agents
- Biological agents
- Temperature

Endurance → Properties ← Degradation

Properties

Part 2

INSTALLATION DAMAGE

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Installation damage (ID)

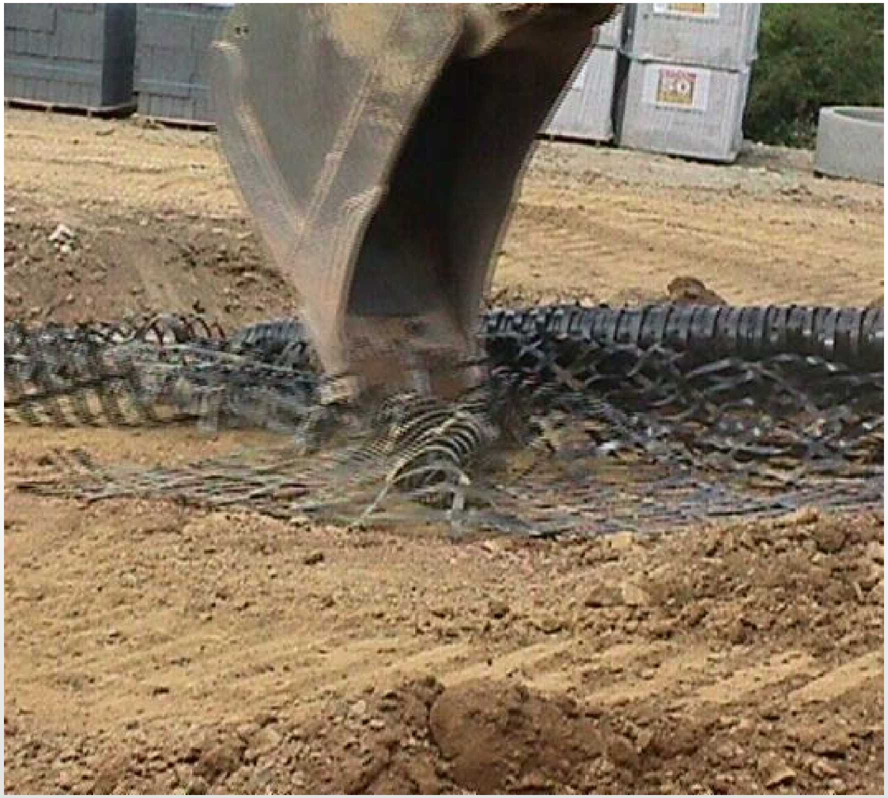
A result of

- Handling and placing the geosynthetics
- Placing and compacting fill materials

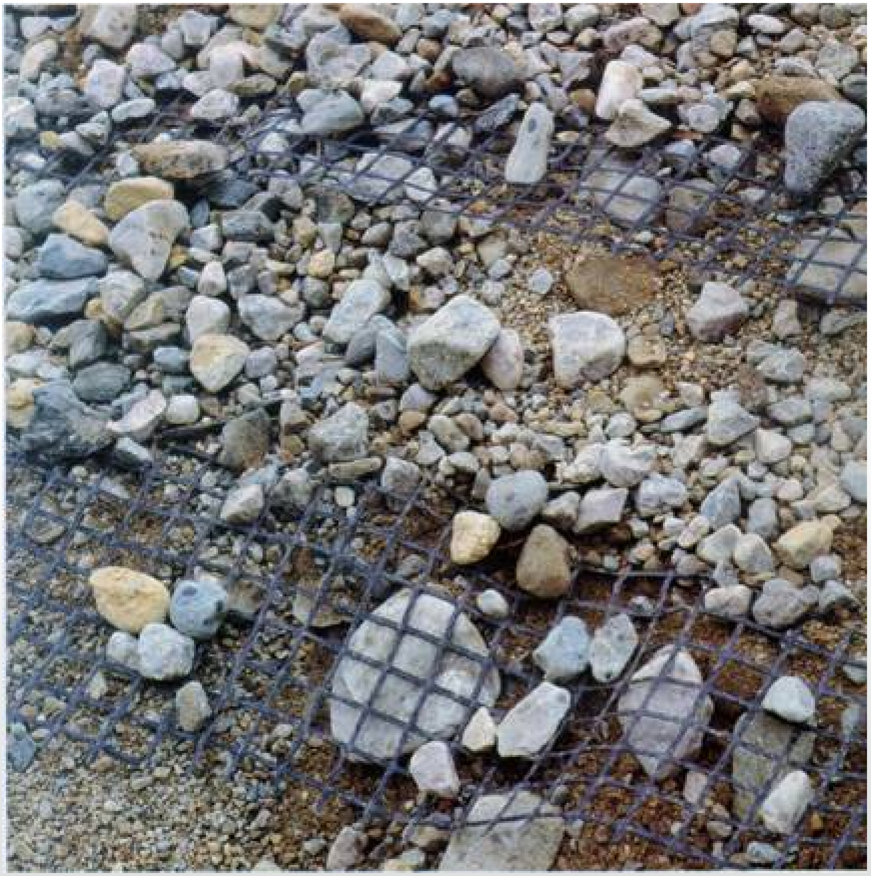
Originates

- Local defects
- Change in properties

Handling and placing the geosynthetics



Handling and placing the geosynthetics
Placing and compacting fill materials



Placing and compacting fill materials

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Consequences of ID

Local defects

- Abrasion
- Puncturing
- Fibre cutting
- Thickness reduction
- Cuts and holes
- Total disintegration

Mechanical properties

- More relevant for reinforcement applications

- Short-term
- Long-term

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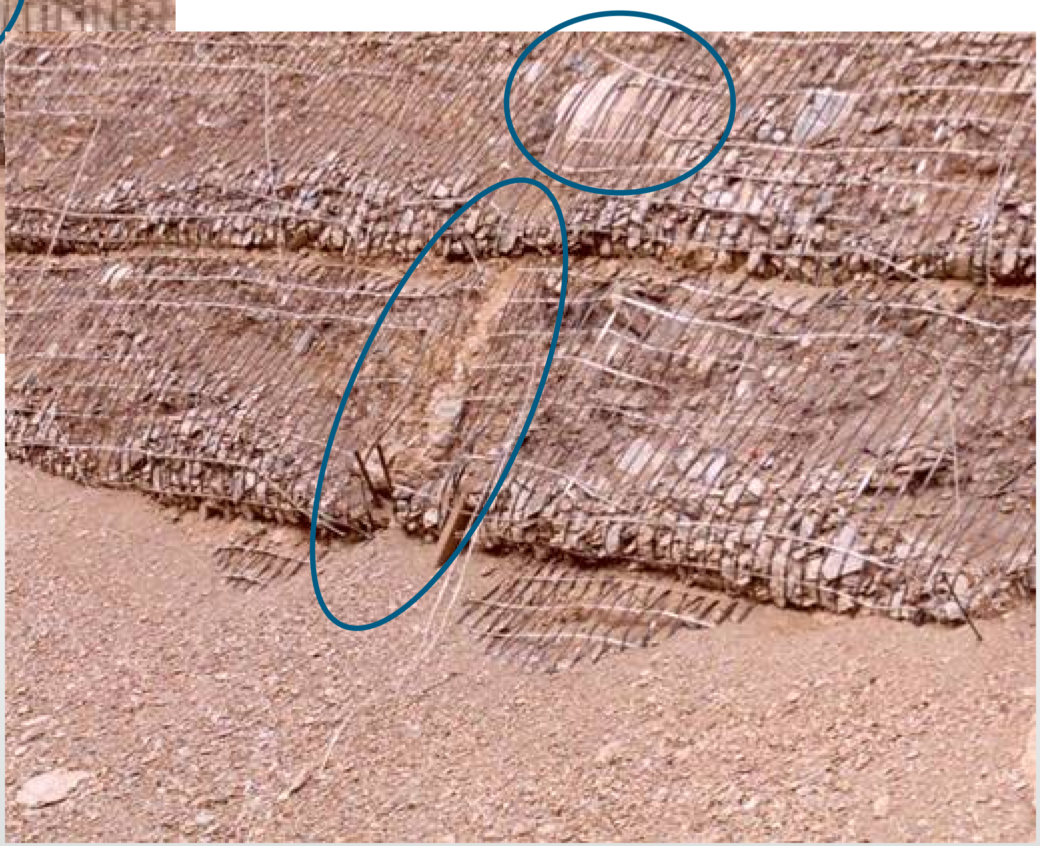
Local defects



Changes in mechanical properties

Application

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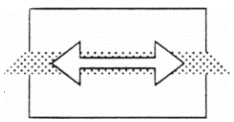
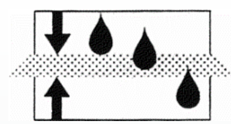
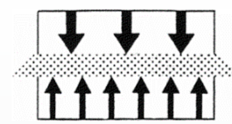
Reinforcement



Strength reduction (can be very important)

Filtration and/or separation



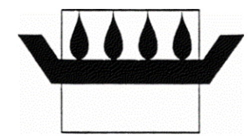


Perforations

⇓

Reduction of effectiveness

Barrier



Initially small cuts

⇓

Large openings

⇓

No longer fulfil their function

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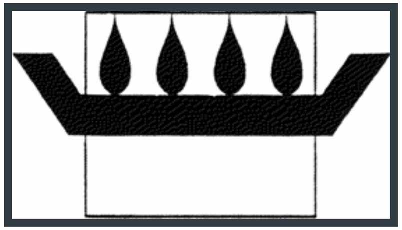


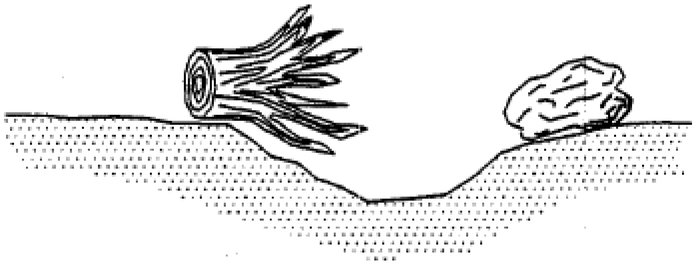
Barrier

@ John Greenwood

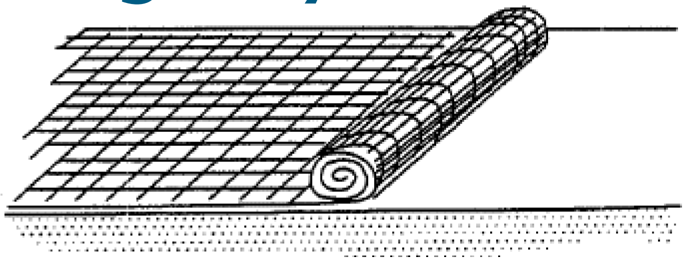
Installation damage
How to avoid:

Perform all operations carefully and, principally, adequately

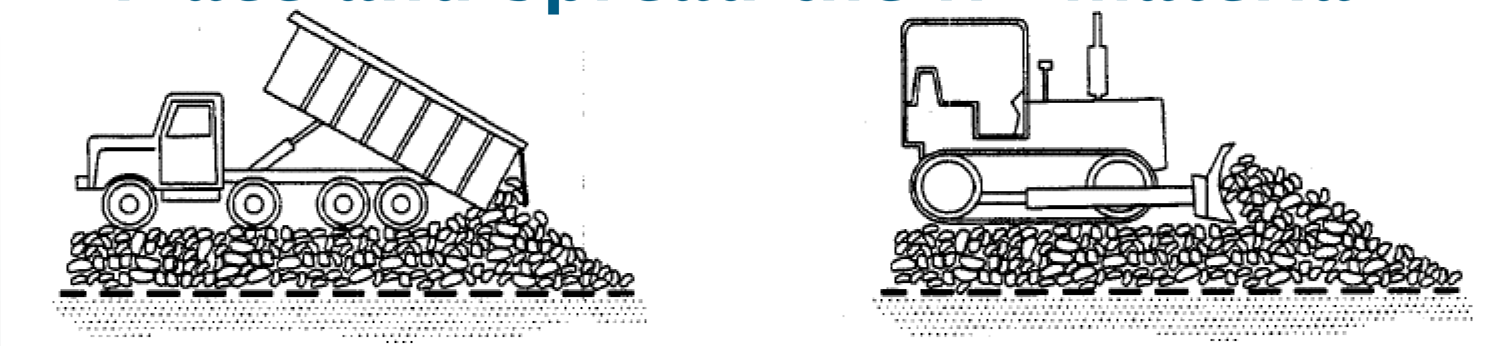
Prepare the foundation layer



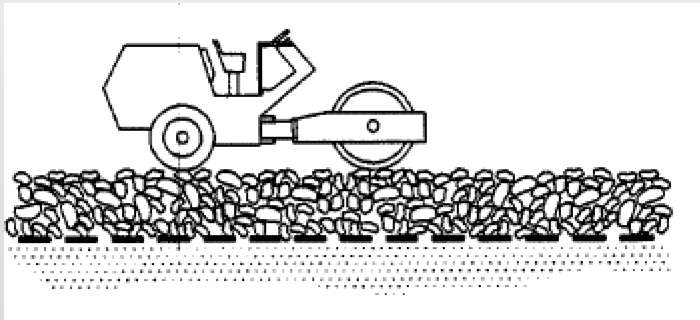
Unroll the geosynthetic



Place and spread the fill material

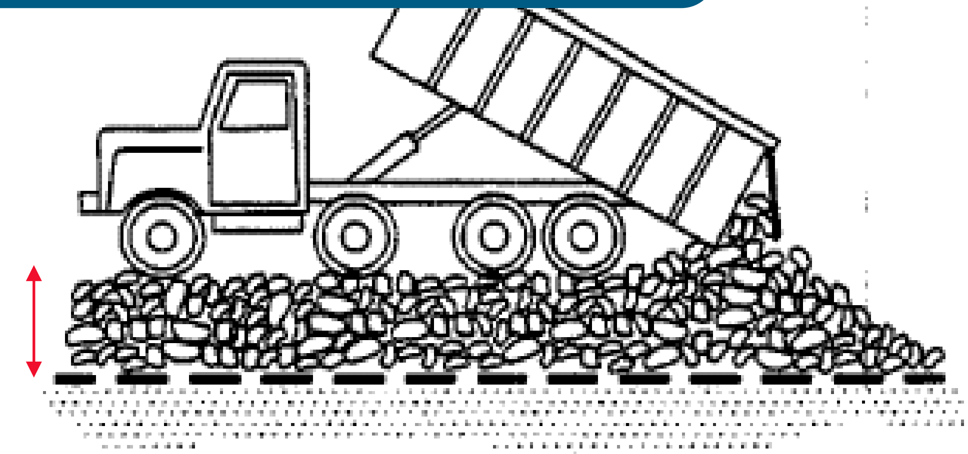


Compact the fill material

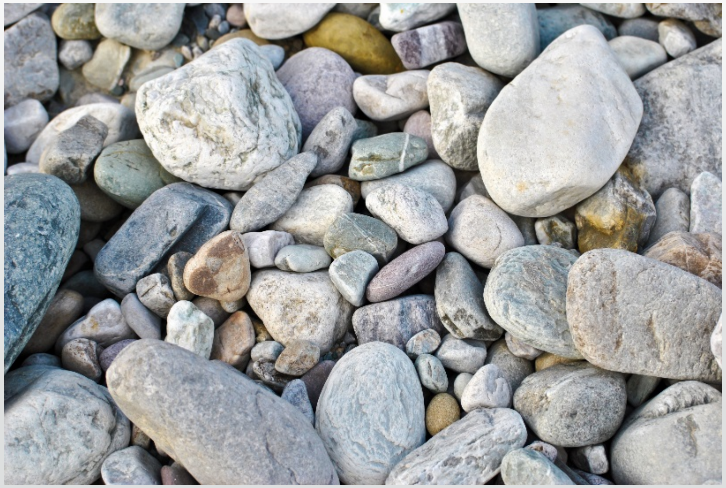


Installation damage
How to avoid:

@ Richardson (1998)



h ≥ 0.15m



Maximum particle size ≤ h/4

Installation damage
How to avoid:

Choose a stronger geosynthetic

Less susceptible to damage

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Installation damage
How to avoid:

Perform all operations carefully and, principally, adequately

Choose a stronger geosynthetic

Installation damage is often unavoidable

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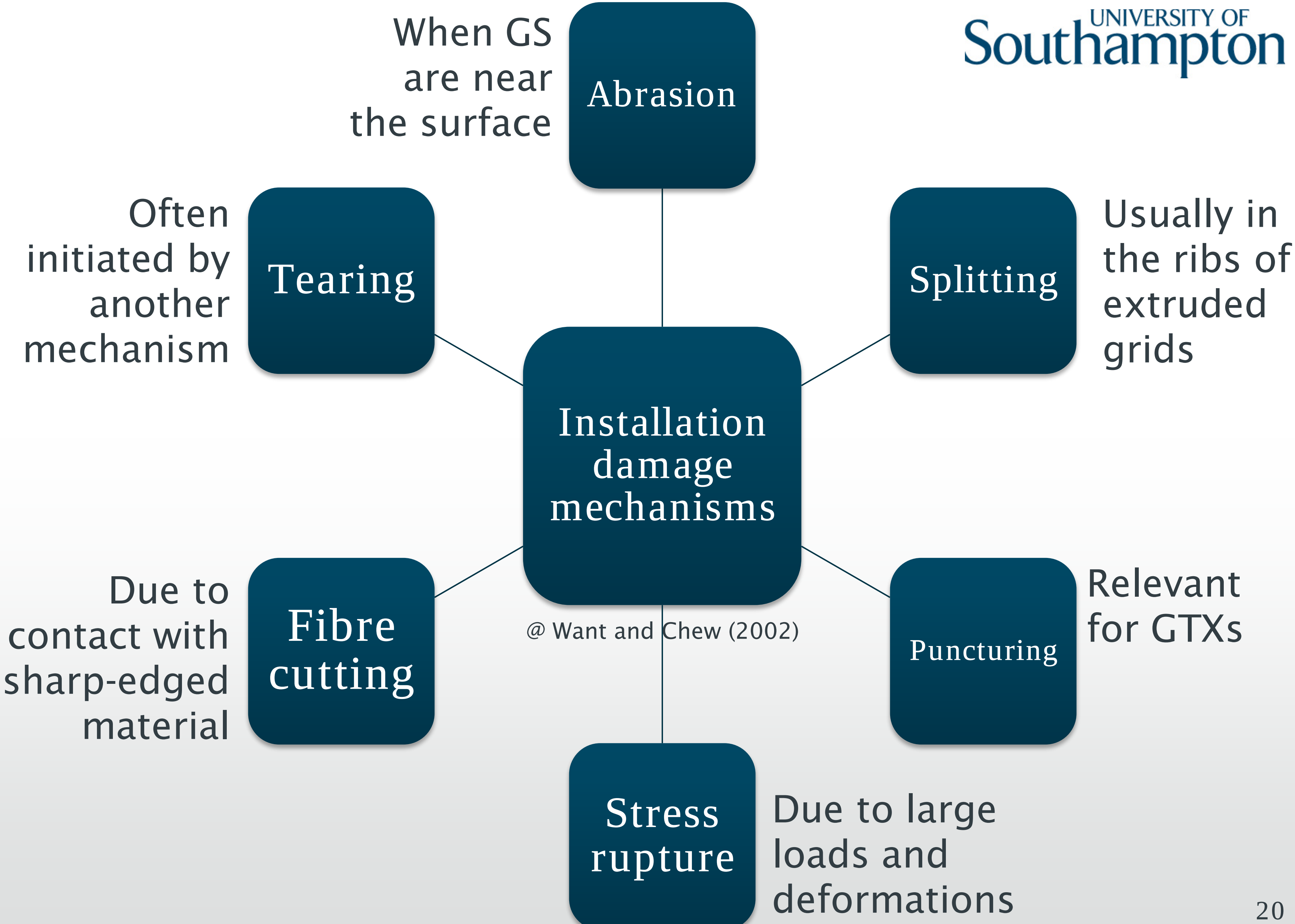

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Installation damage depends on:

- **Subsoil**
  - Stiffness
  - Strength
- **Geosynthetic**
  - Structure
  - Constituent polymer
  - Thickness
- **Fill material**
  - Grain size
  - Angularity
- **Procedures**
  - Equipment
  - Thickness of layers
- **Climatic conditions**
  - Temperature
  - Water

Part 3

MAIN CONSEQUENCES OF INSTALLATION DAMAGE

Consequences of installation (DD ISO/TS 13434:2008)

- Light damage
  - Scuffing
  - Scratches on the surface
  - Fibre abrasion
- Severe damage
  - Cuts
  - Tears
  - Perforations

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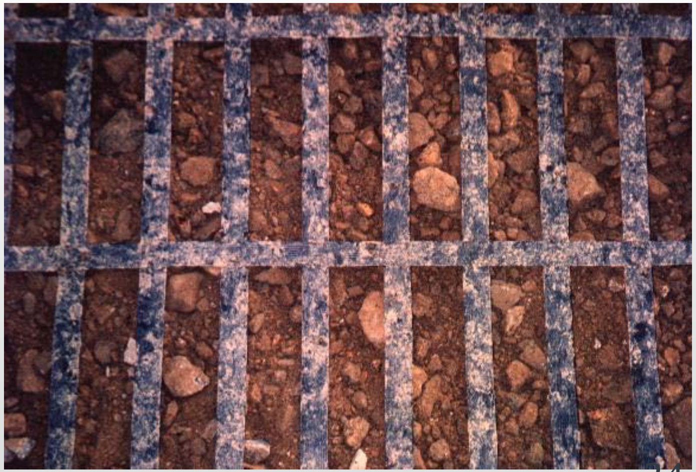
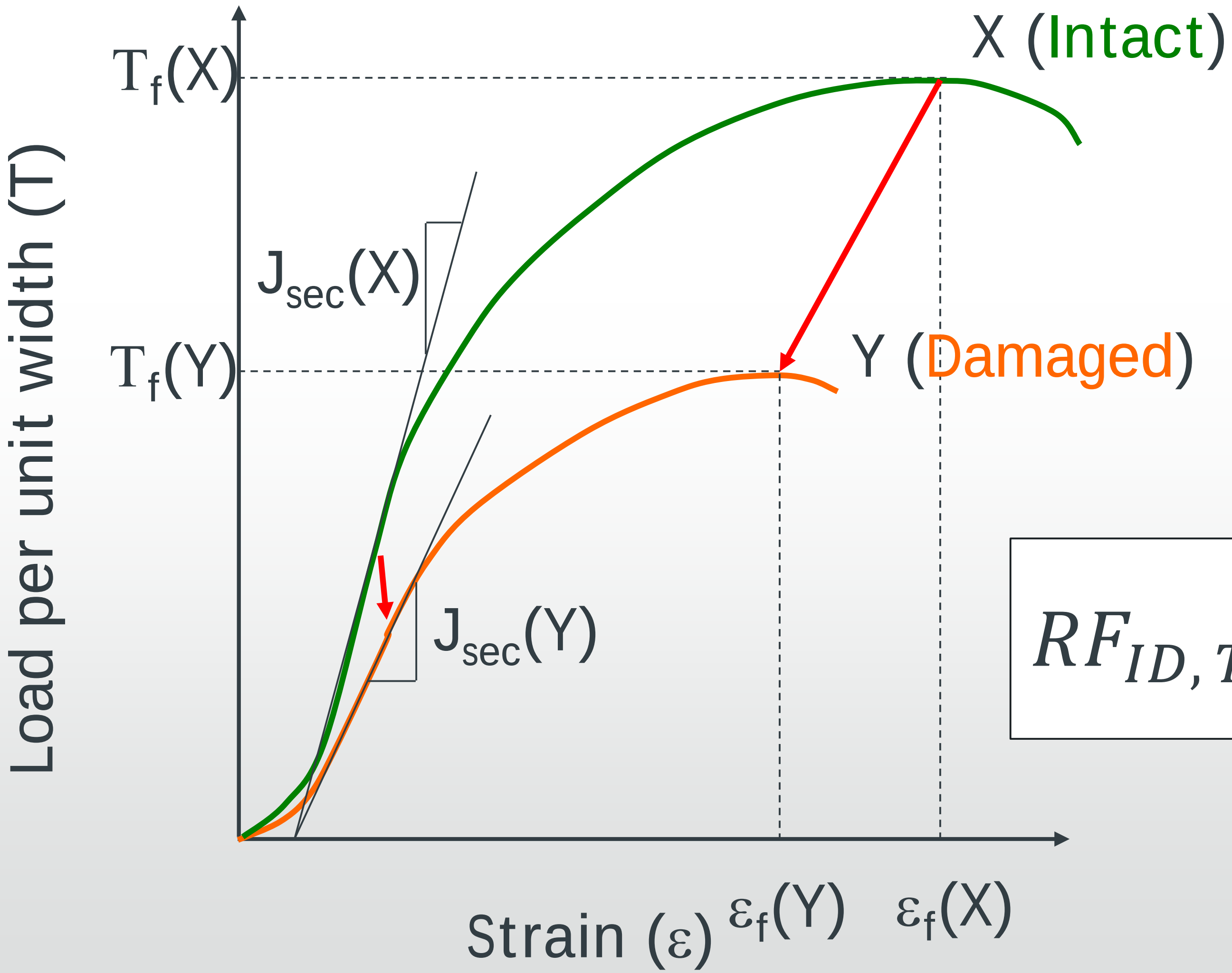
Visual inspections

- Typical observations
  - Accumulation of dust and dirt
  - Local defects
- Classifications
  - Number and size of openings
  - Very subjective / operator dependent



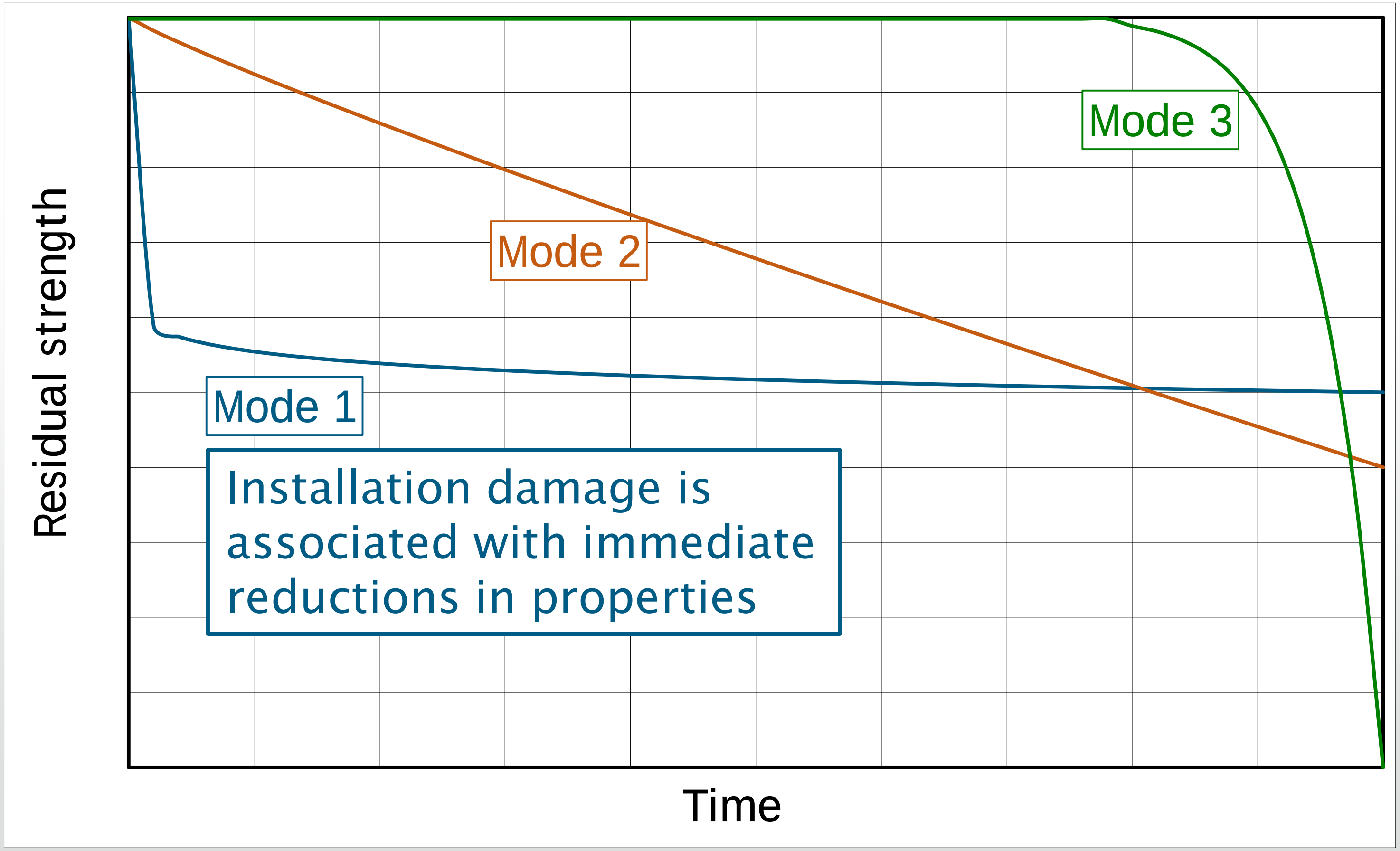
Mechanical response – short-term



$$RF_{ID,T} = \frac{T_{und}}{T_{dam}}$$

Mechanical response – long-term

Creep rupture – sustained load
Apart from any environmental or installation damage effects



Design strength

- Soil reinforcement (EN ISO 20432: 2007)

$$T_D = \frac{T_{char}}{RF_{CR} \times RF_{ID} \times RF_W \times RF_{CH} \times f_s}$$

Reduction factors for

- RF_{CR} - creep rupture
- RF_{ID} - installation damage
- RF_W - weathering
- RF_{CH} - chemical agents
- f_s - Factor of safety allowing for statistical variation (extrapolation over long periods)

Hydraulic properties

- Local defects can affect hydraulic properties
  - Cuts, holes, tearing
    - normal permeability
  - Abrasion, reduction of thickness, stress rupture
    - in-plane permeability

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Long term discharge capacity

- Discharge capacity (Greenwood, Schroeder & Voskamp 2012)

$$Q_{LT} = \frac{Q_{index}}{RF_W \times RF_{Comp} \times RF_{IN} \times RF_{CC} \times RF_{BC} \times RF_{ID}}$$

Reduction factors for

  - RF_W - weathering
  - RF_{Comp} - compressive creep
  - RF_{IN} - time-dependent intrusion of the soil
  - RF_{CC} - chemical clogging
  - RF_{BC} - biological clogging
  - RF_{ID} - installation damage

Long term permeability

- Permeability (Greenwood, Schroeder & Voskamp 2012)

$$k_{LT} = \frac{k_{index}}{RF_W \times RF_{Comp} \times RF_{IN} \times RF_{CC} \times RF_{BC} \times RF_{ID}}$$

Reduction factors for

  - RF_W - weathering
  - RF_{Comp} - compressive creep
  - RF_{IN} - time-dependent intrusion of the soil
  - RF_{CC} - chemical clogging
  - RF_{BC} - biological clogging
  - RF_{ID} - installation damage

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Reduction factors

- Tensile strength
- To be obtained from installation damage tests:
  - project conditions or similar
  - universal test procedure
- Interpolations (EN ISO/TR 20342:2007)
  - for the same geosynthetic using measurements with different soils
  - for other products within the same product line

Installation damage versus function

Degree of damage **prevents fulfilling** the function(s)

Damaged but **still able to perform** the intended function(s)

Installation damage Assessment:

- Laboratory simulations
- Real scale simulations
- Exhumation of installed materials

Specifications and / or robustness classes

Robustness classes (usually not applicable to reinforcements)

- Classes:
  - type of geosynthetic
  - constituent polymer
  - fill material
  - installation method

- Minimum values for the strength
- Minimum values for the mass per unit area
- Severity of application

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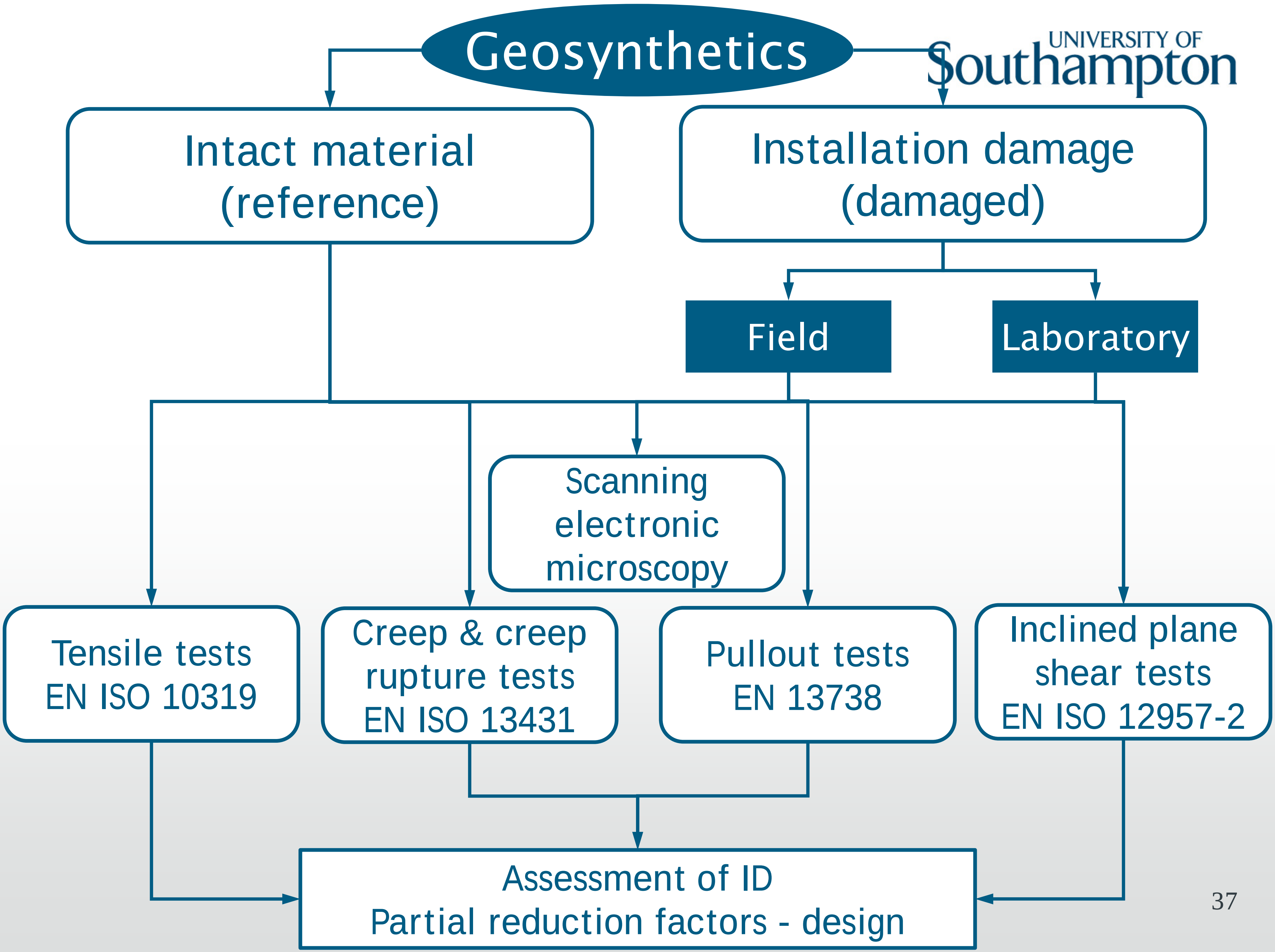
Robustness classes (usually not applicable to reinforcements)

- Some reference documents
  - Germany – FGSV Merkblatt (2005)
  - Nordic countries – NorGeoSpec 2012
  - USA – AASHTO M288-06

Part 4

SOME RESULTS. CONSEQUENCES FOR DESIGN


Geosynthetics
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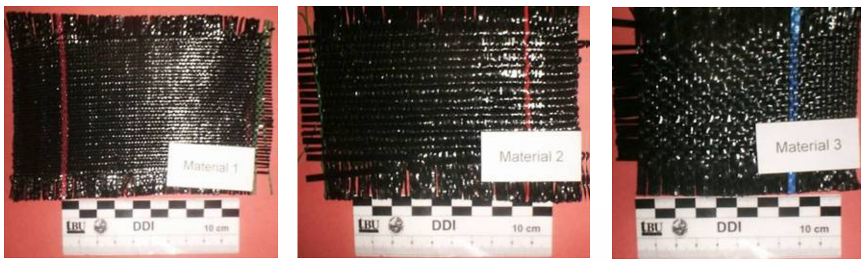
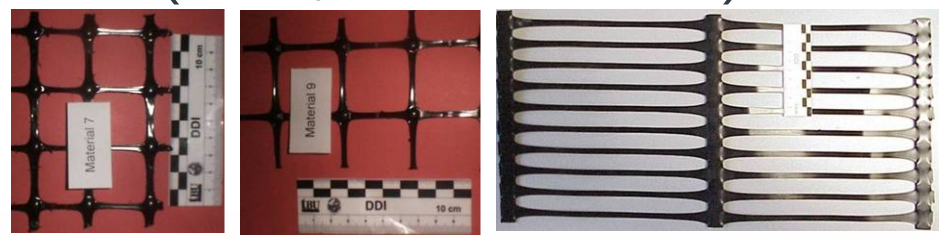
Intact material (reference)
Installation damage (damaged)
Field
Laboratory
Scanning electronic microscopy
Tensile tests EN ISO 10319
Creep & creep rupture tests EN ISO 13431
Pullout tests EN 13738
Inclined plane shear tests EN ISO 12957-2
Assessment of ID
Partial reduction factors - design

Geosynthetics

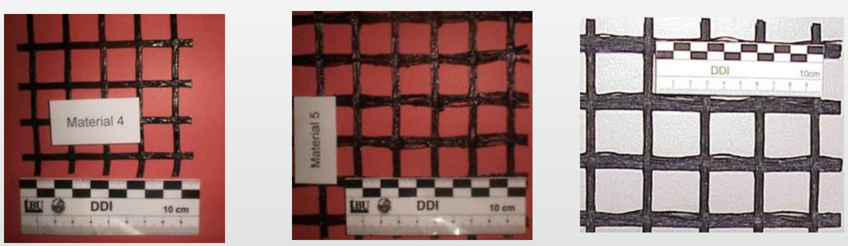
Geotextiles: Woven PP-tapes
(GTX1, GTX2 and GTX3)



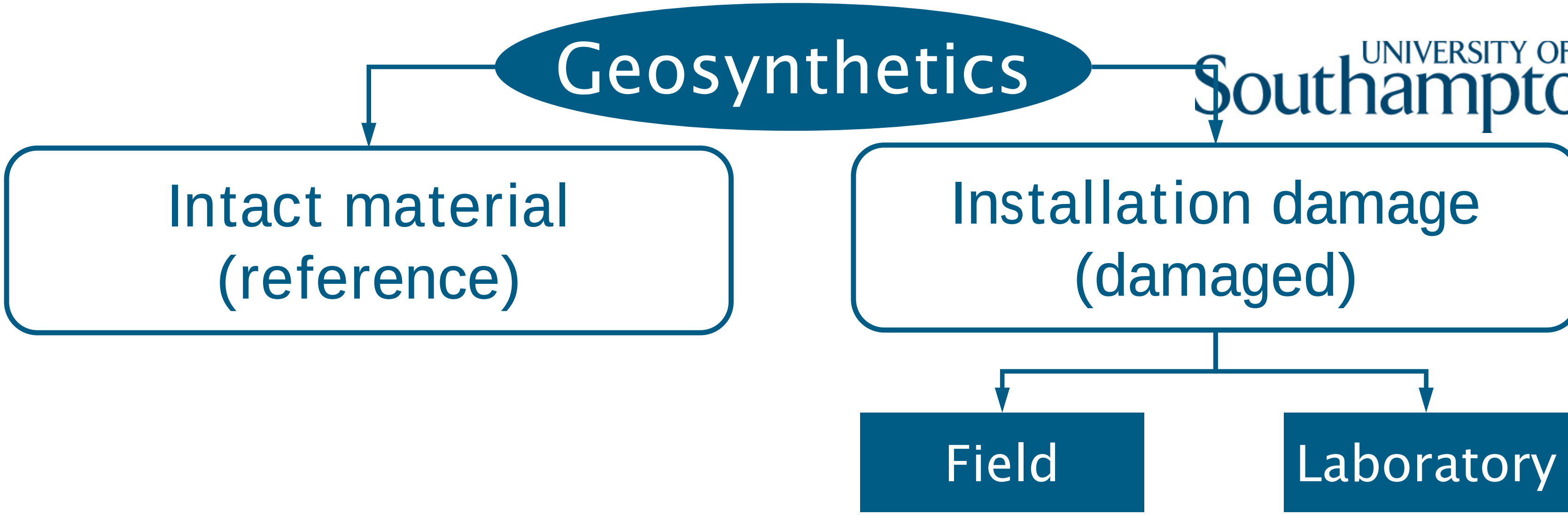
Extruded Geogrids
(GGe1, GGe2 and GGe3)



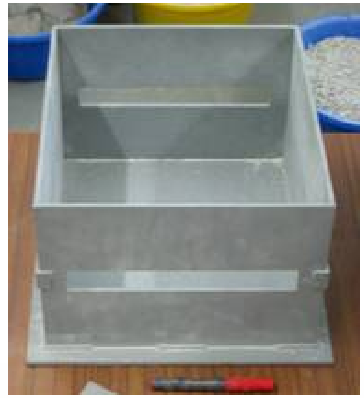
Woven Geogrids
(GGw1, GGw2 and GGw3)

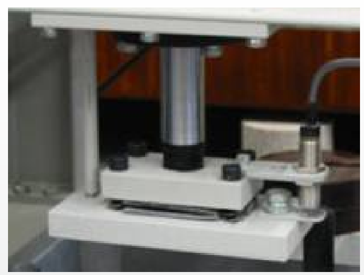


Reinforcement Geocomposites:
(GC1 and GC2)


Geosynthetics
Intact material
(reference)
Installation damage
(damaged)
Field
Laboratory

Laboratory simulations





Container:

- 300 x 300 mm^2
- 150 mm high

Aggregate:

- Sintered aluminium oxide
- 5 mm to 10 mm

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Simulation in laboratory

ENV ISO 10722-1:1998	EN ISO 10722:2007
Stress range: 5 – 900 kPa	Stress range: 5 – 500 kPa
tried to reproduce field conditions in laboratory	index test to assess mechanical damage under repeated loading

Cyclic loading:
Frequency of 1 Hz; 200 loading cycles

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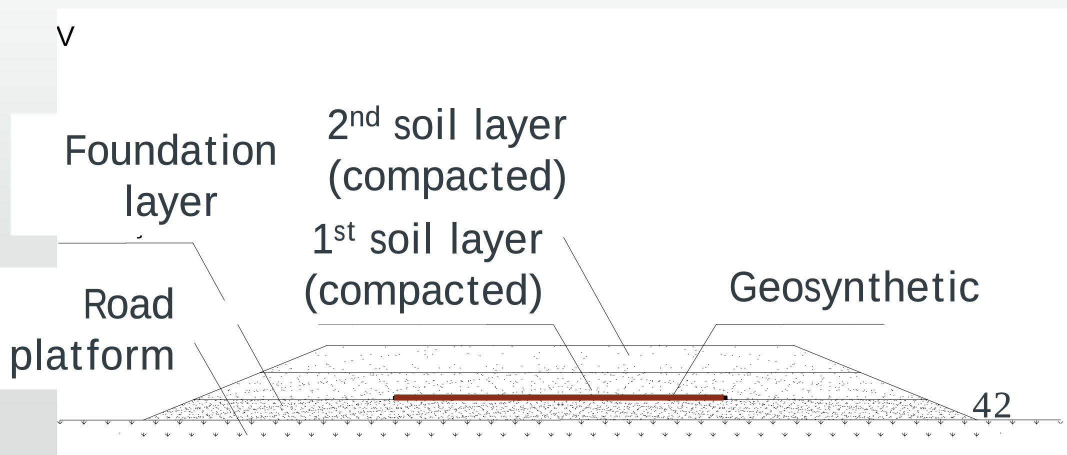
Field trials – exhumation after installation






- No standard procedure
- Temporary embankments (3 different building sites)
- 2 compacted soil layers above the geosynthetics (0.20m high each)

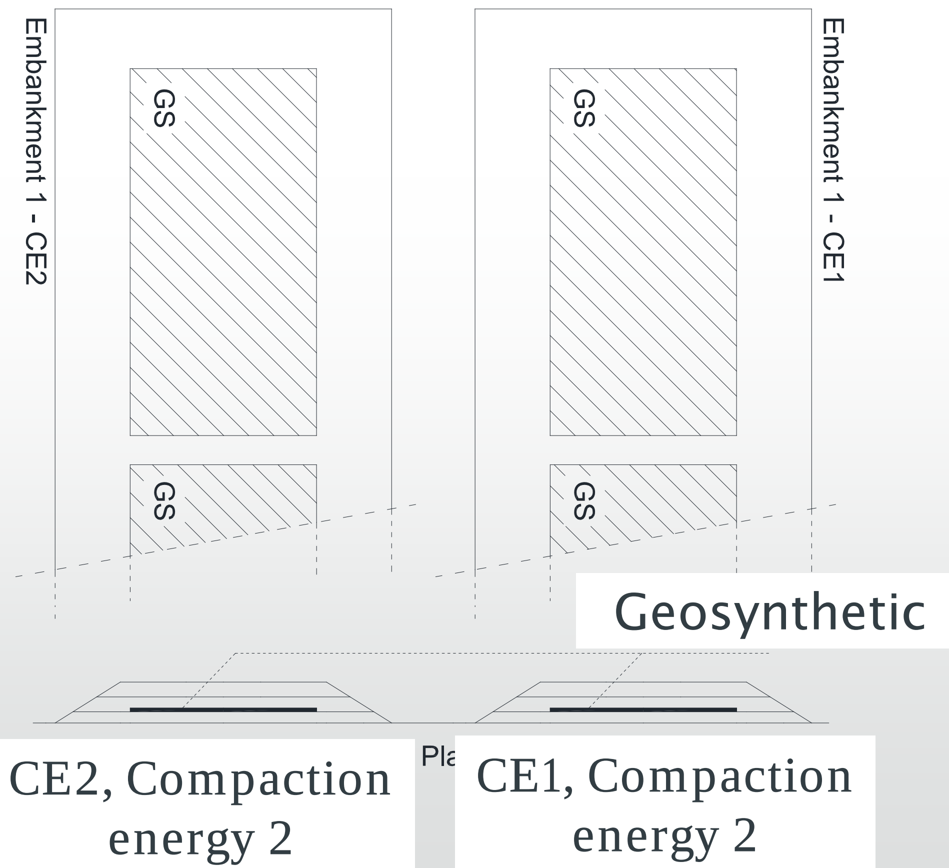


Field trials – exhumation after installation

Compaction energy:

- CE1 - 90%
- CE2 - 98%

standard Proctor



Field trials – exhumation after installation

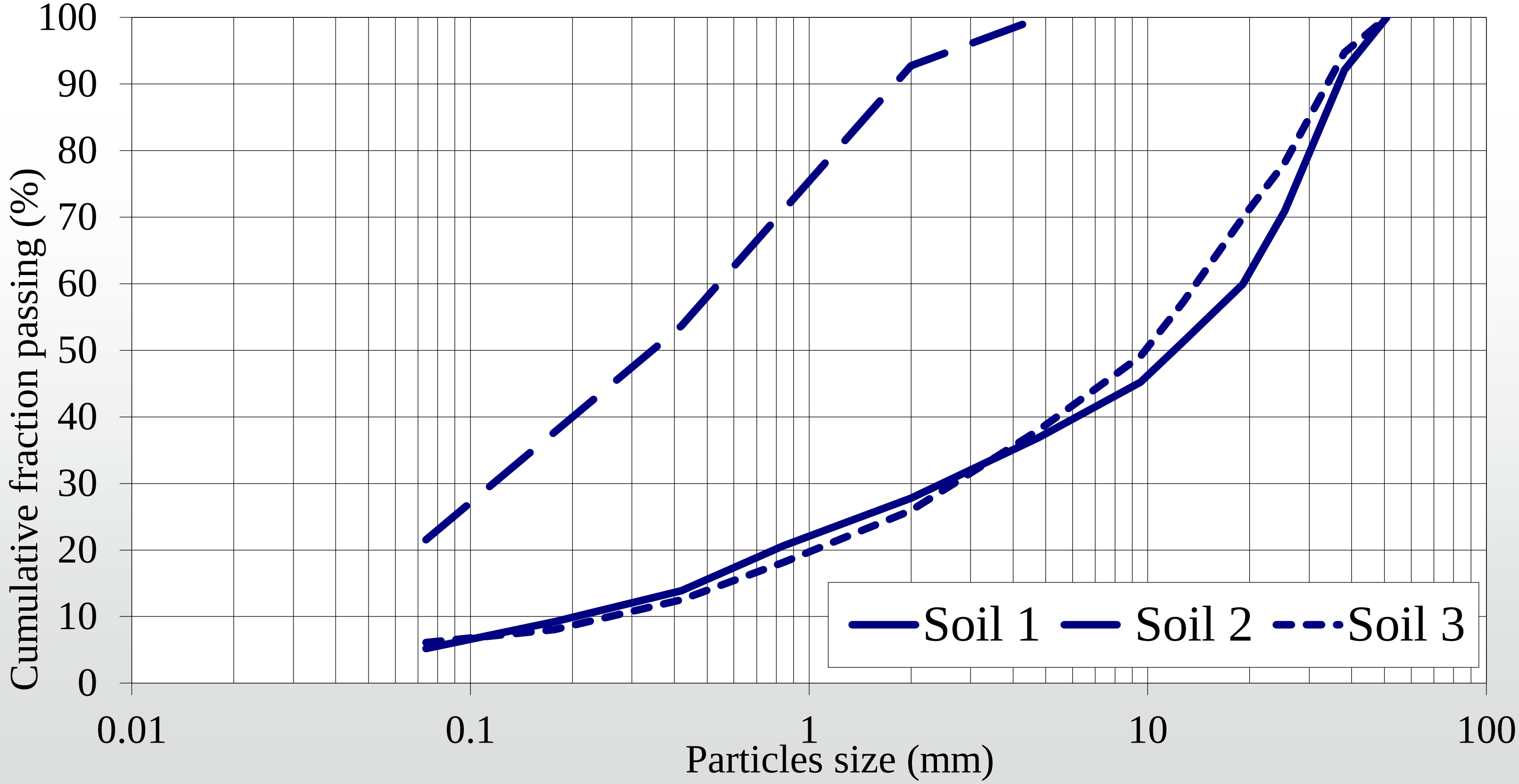
Field trials – exhumation after installation

Exhumation – two stages

Field trials – exhumation after installation

Soils 1 and 3 – Aggregate used in road construction
Soil 2 – Residual soil from granite

D_{50}(mm): 11.78 (S1)
9.88 (S3)
0.38 (S2)



Installation damage - summary

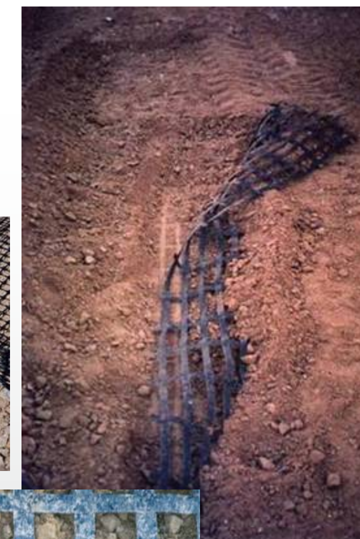
Type of ID test	Laboratory	Field					
Geosynthetic	Synthetic aggregate	Soil 1		Soil 2		Soil 3	
		CE1	CE2	CE1	CE2	CE1	CE2
GTX1	x	x	x	-	x	-	-
GTX2	x	x	x	-	x	-	-
GTX3	x	x	x	-	x	x	x
GGw1	x	-	-	x	x	-	-
GGw2	x	x	x	x	x	-	-
GC1	x	-	-	x	x	-	-
GGe1	x	x	x	x	x	x	x
GC2	x	x	x	x	x	-	-
GGe2	x	x	x	x	x	-	-
GGw3	x	-	-	-	-	x	x
GGe3	x	-	-	-	-	x	x

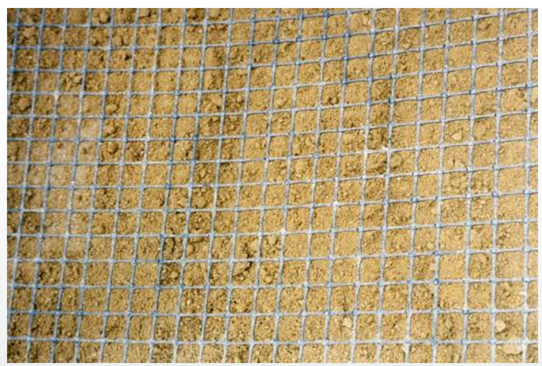
48 different types of samples

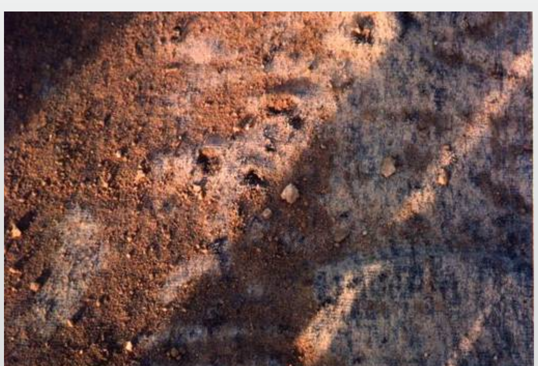
Field trials – exhumation after installation

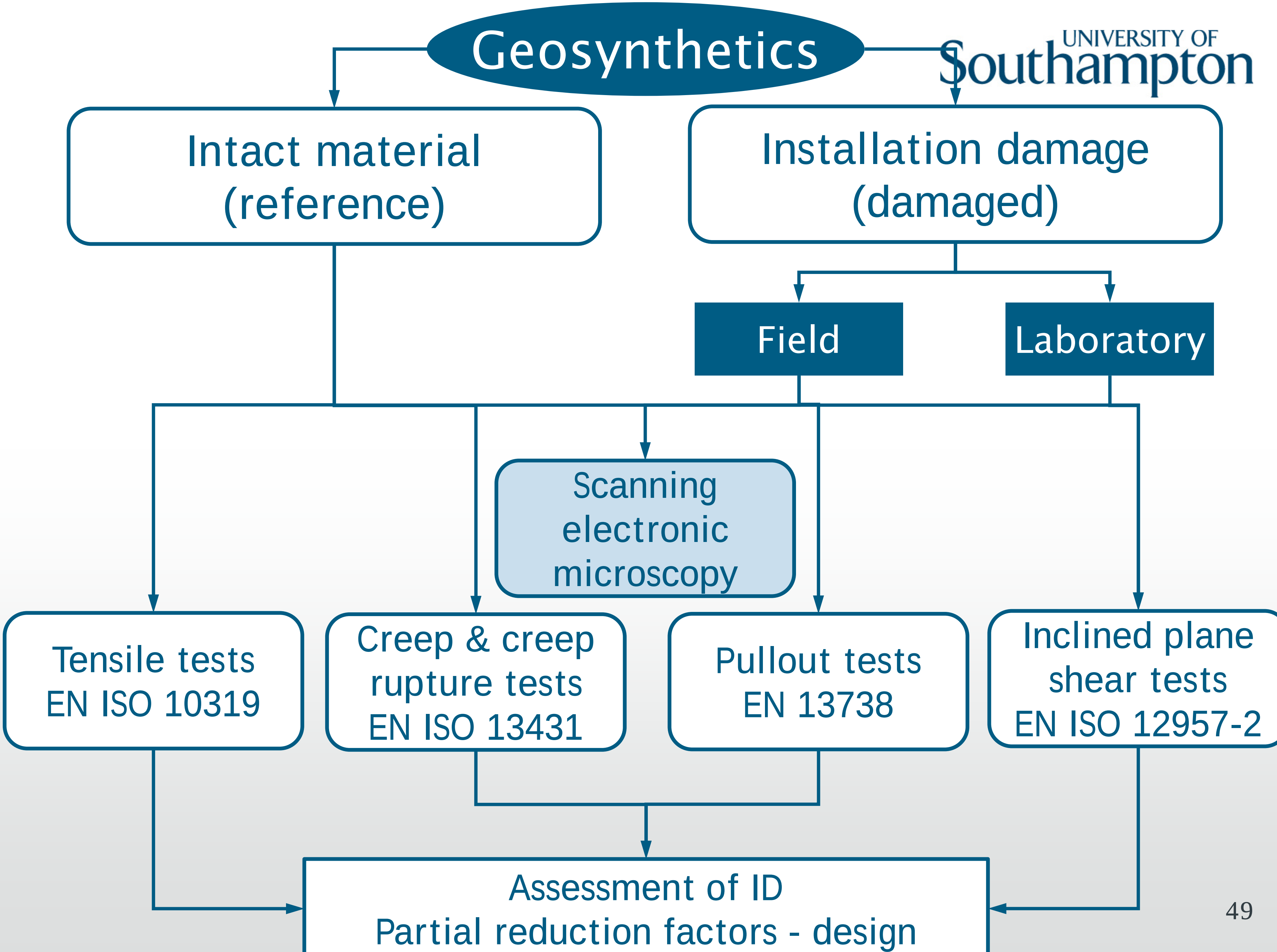










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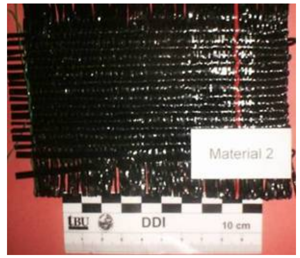
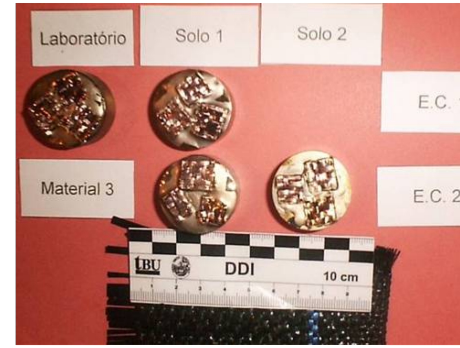
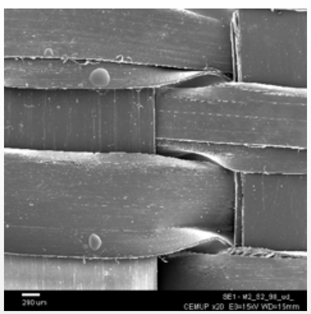
Scanning electronic microscopy

- Geotextile GTX2

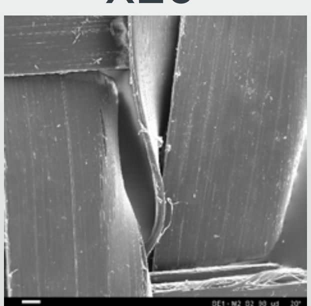




Undamaged

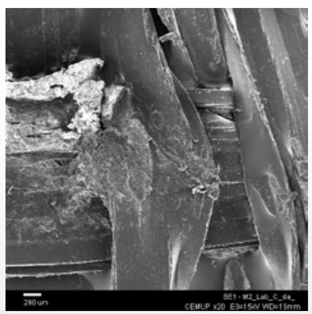


x10

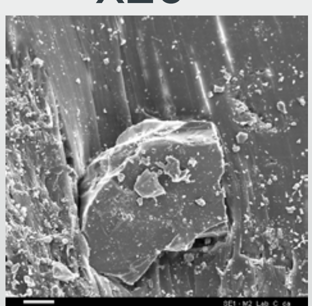


x50

ID Laboratory



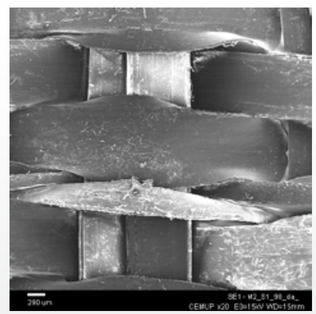
x20



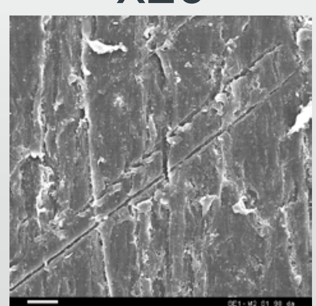
x500

ID Field

Soil 1 CE1

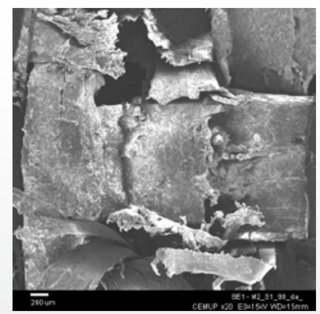


x20

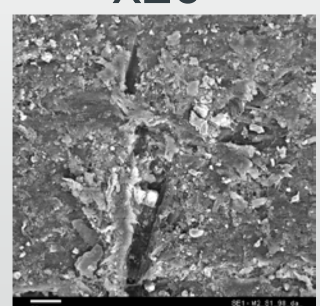


x500

Soil 1 CE2

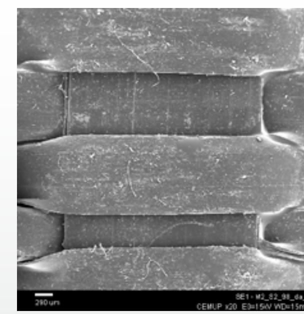


x20

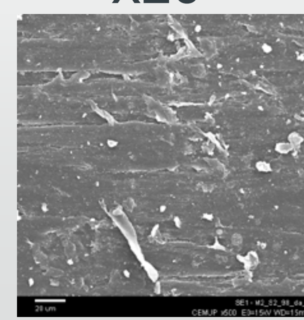


x500

Soil 2 CE2



x20



x500

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Geosynthetics

- Intact material (reference)
- Installation damage (damaged)
  - Field
  - Laboratory

Scanning electronic microscopy

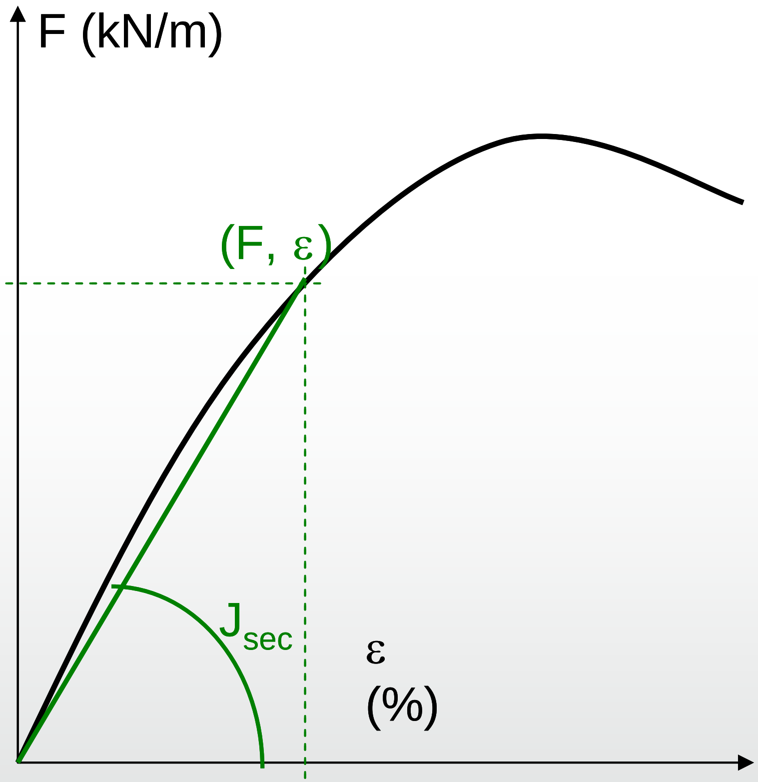
Tensile tests EN ISO 10319

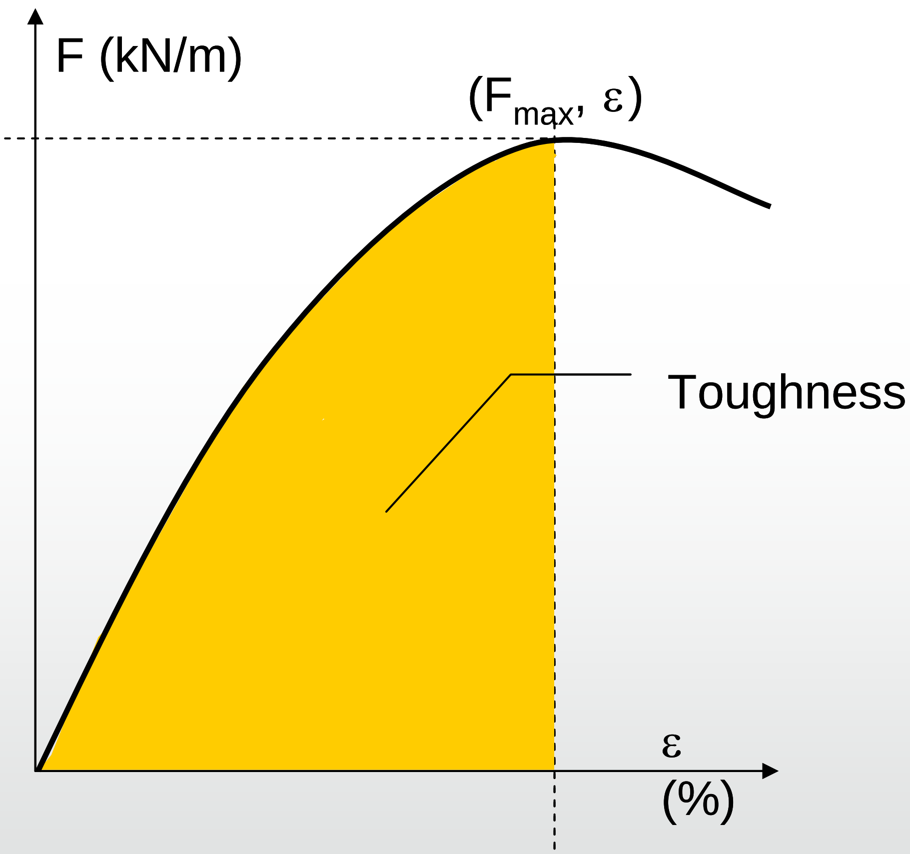
Creep & creep rupture tests EN ISO 13431

Pullout tests EN 13738

Inclined plane shear tests EN ISO 12957-2

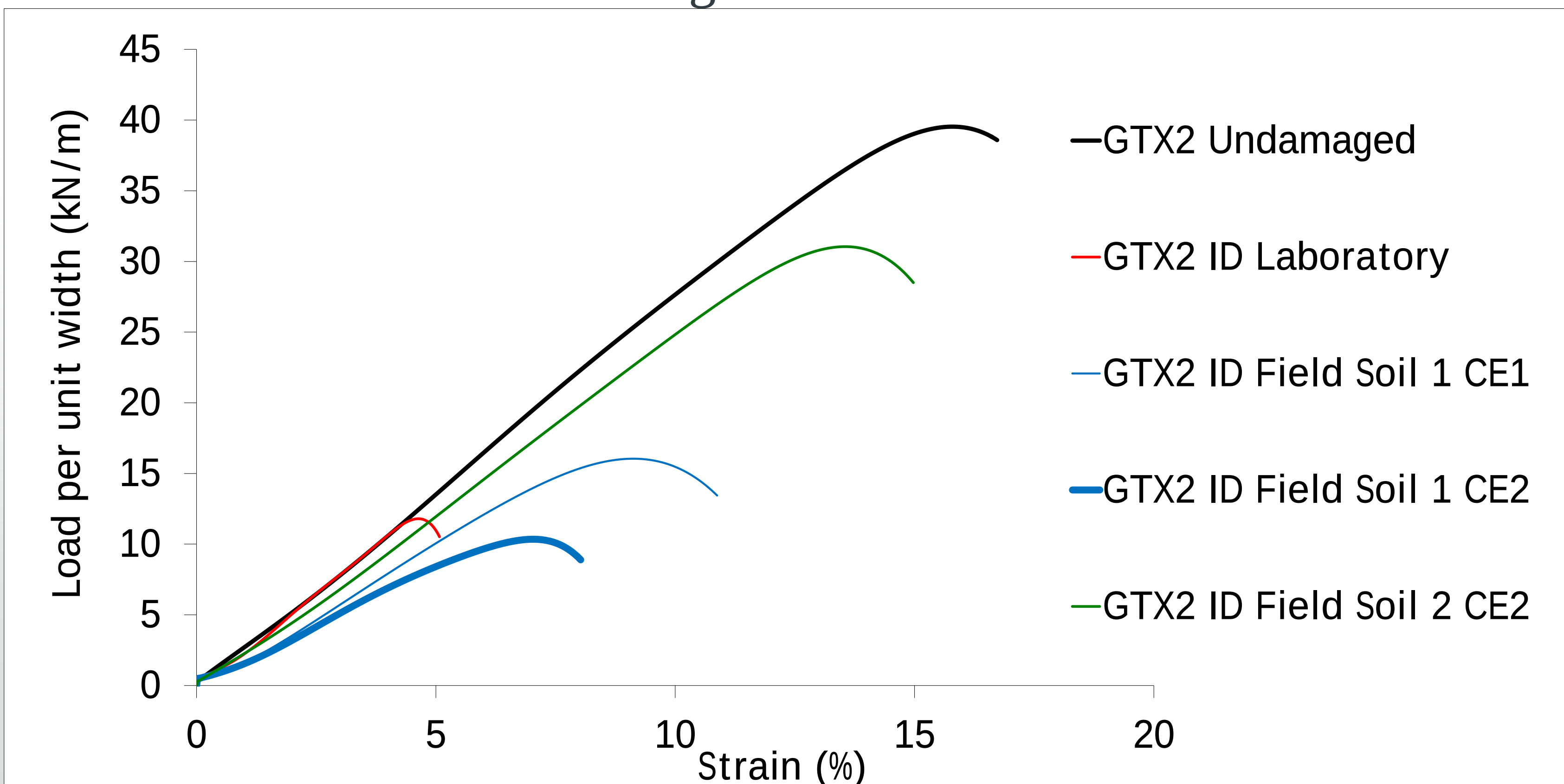
Tensile tests – short-term behaviour





Tensile tests – short-term behaviour

- Geotextile GTX2 
  - reduced tensile strength & corresponding strain
  - reduced stiffness and toughness



Geotextiles:

Woven PP-tapes

GTX1

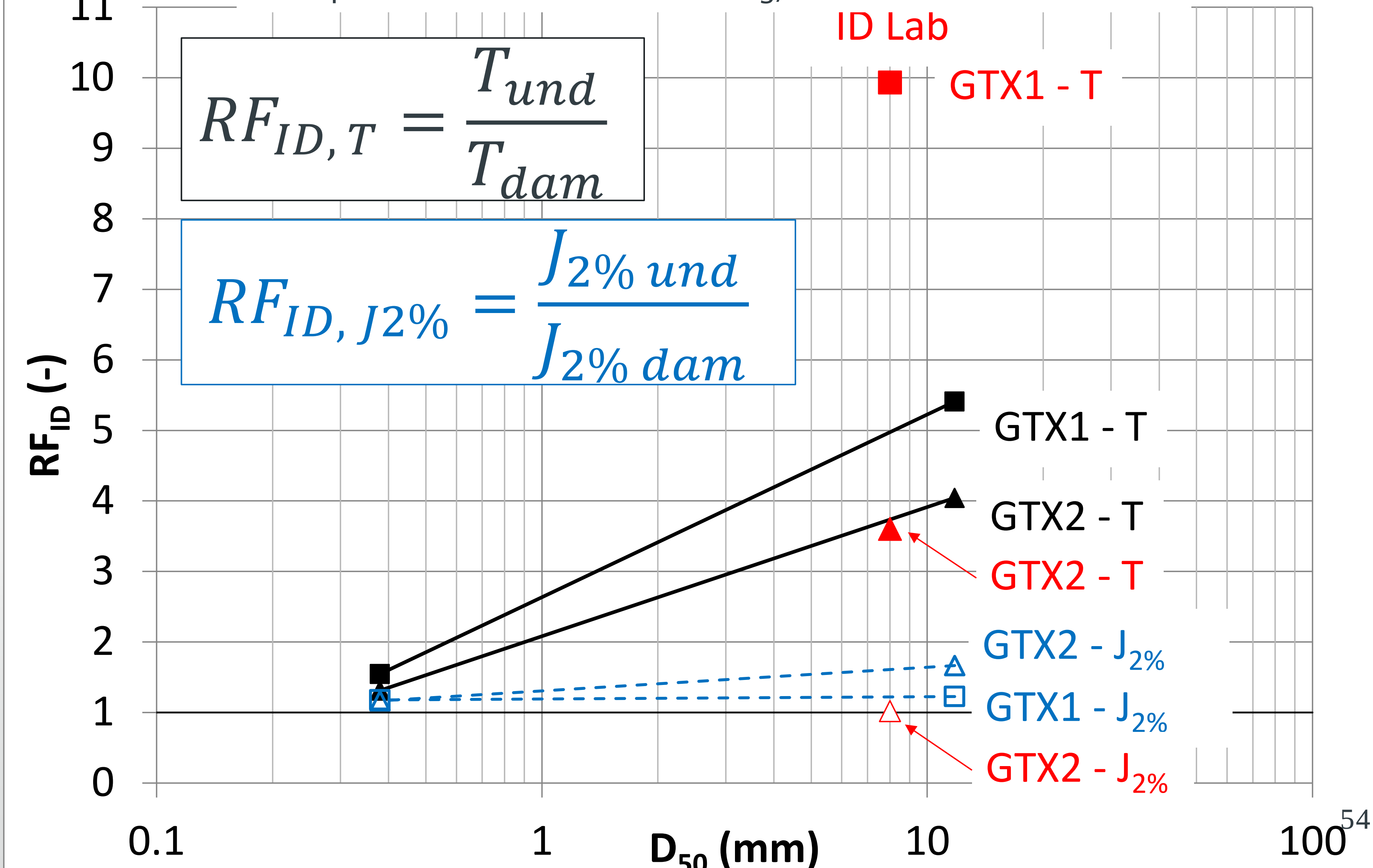
GTX2

Nominal strength: 22 44 kN/m

Mass per unit area: 110 220 g/m²

$$RF_{ID,T} = \frac{T_{und}}{T_{dam}}$$

$$RF_{ID,J2\%} = \frac{J_{2\%\,und}}{J_{2\%\,dam}}$$



Geotextiles:

Woven PP-tapes

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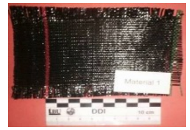
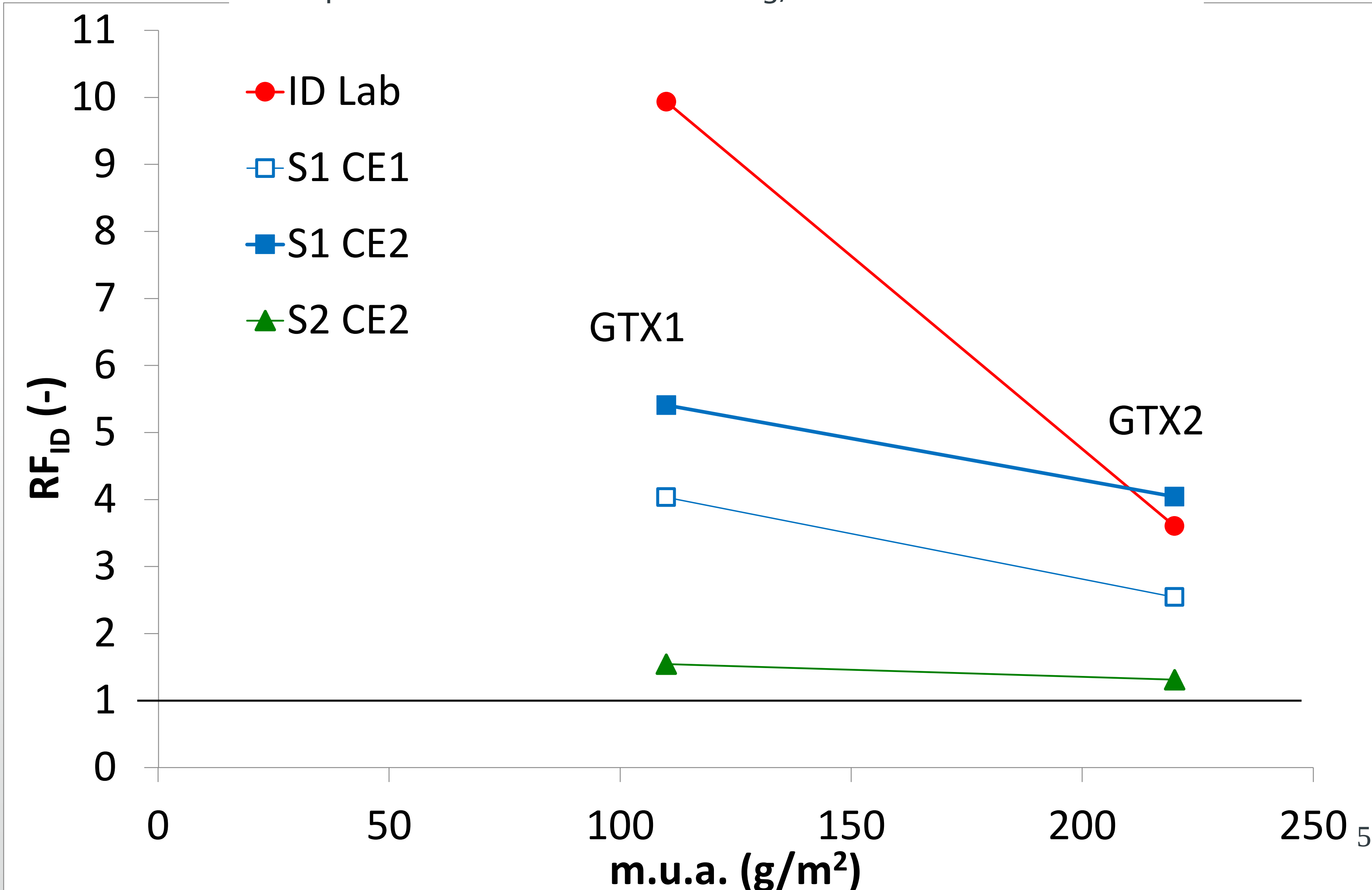


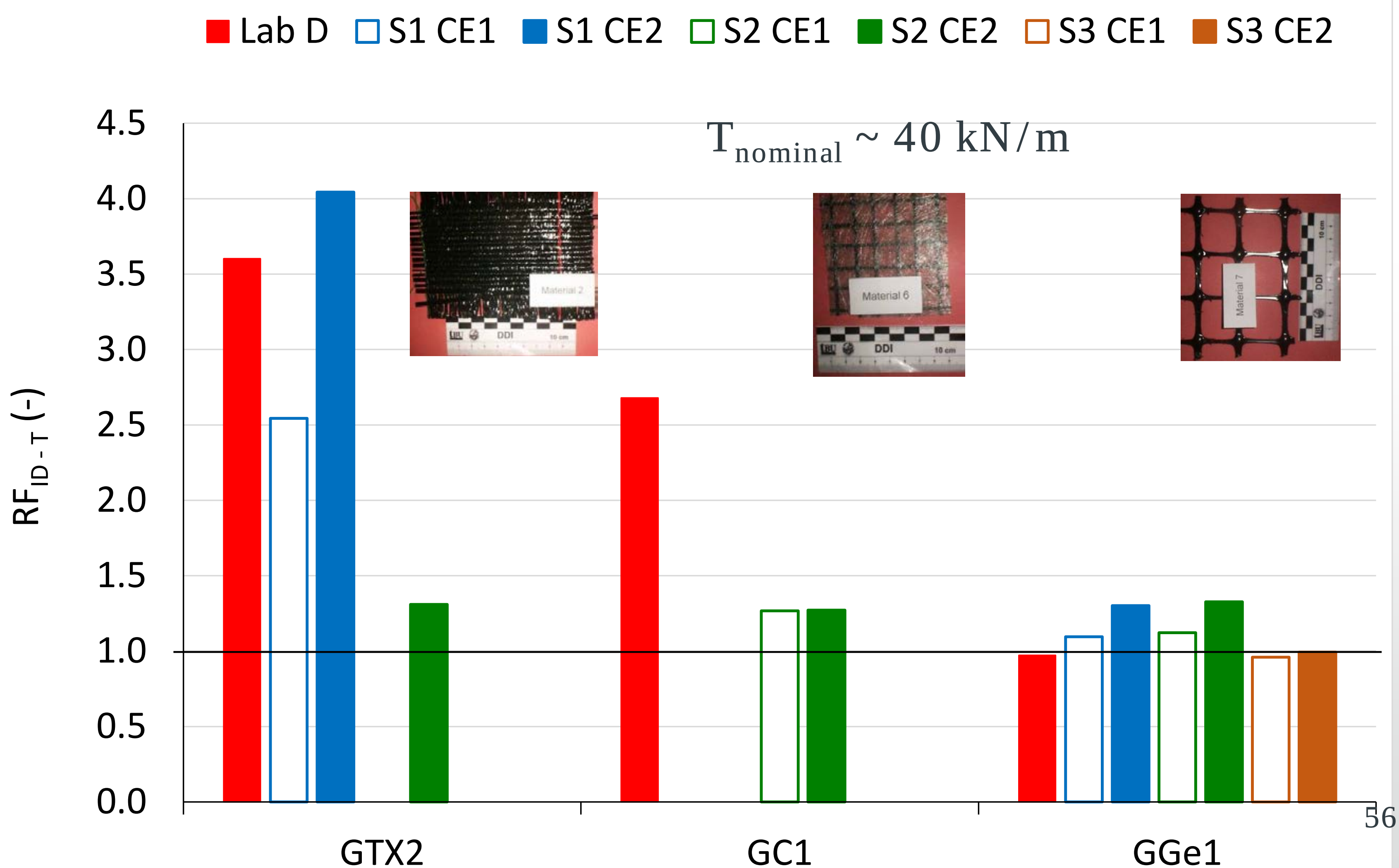
GTX1

GTX2

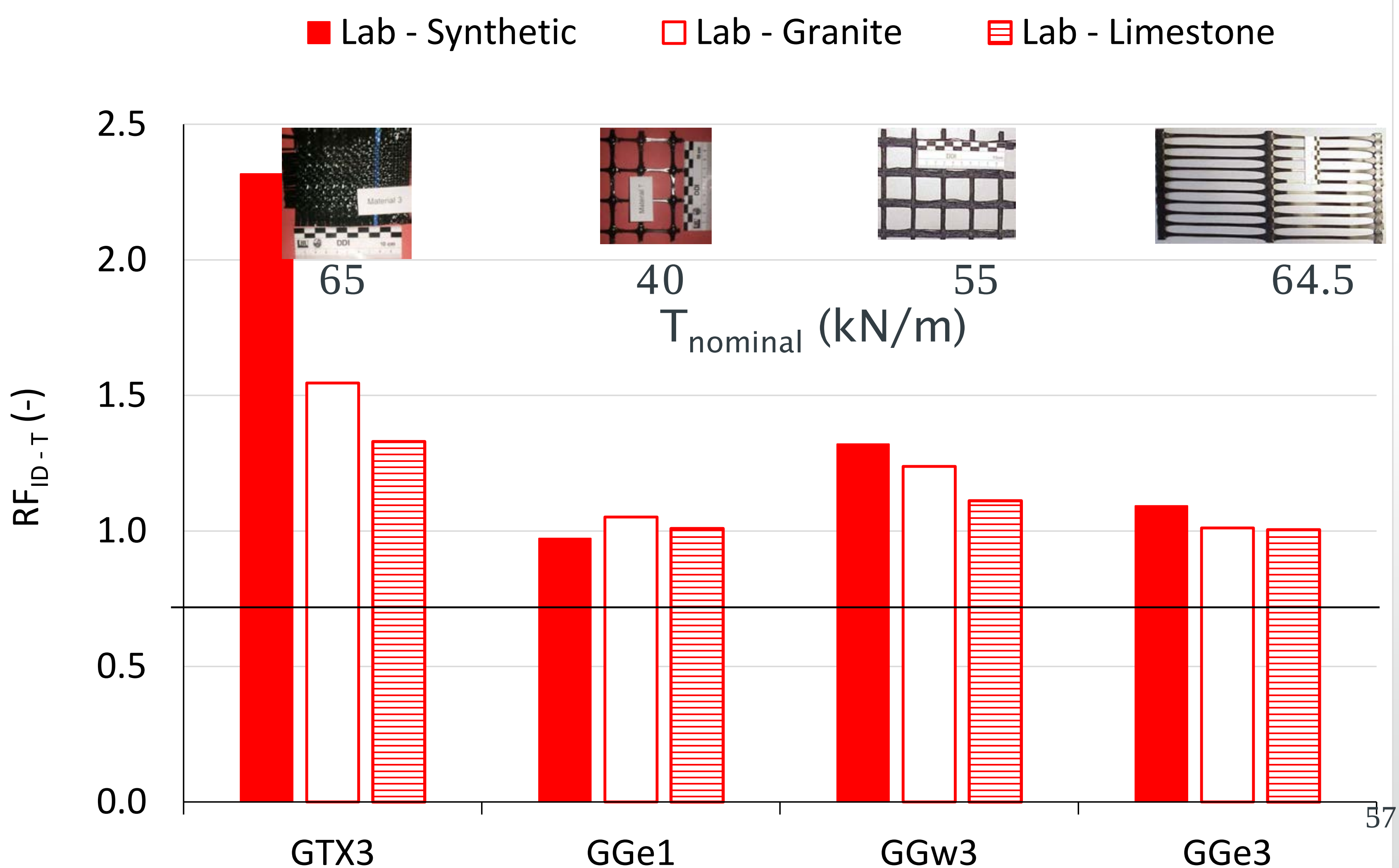
Nominal strength: 22 44 kN/m
Mass per unit area: 110 220 g/m²



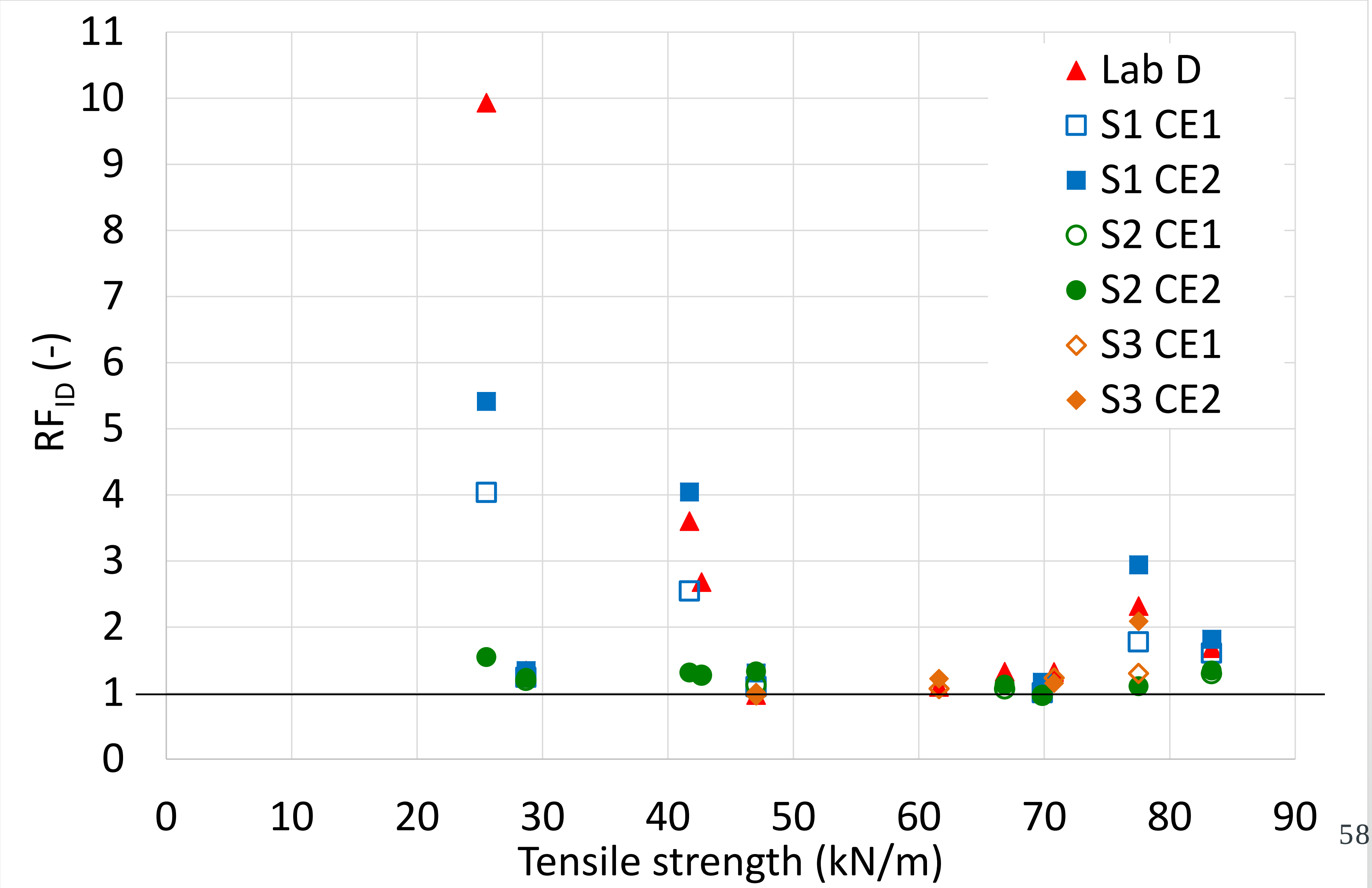
Tensile tests – $RF_{ID,T}$ – Geosynthetic



Tensile tests – $RF_{ID,T}$ – Lab. Damage



Tensile tests – $RF_{ID, T}$



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Geosynthetics

Intact material (reference)

Installation damage (damaged)

- Field
- Laboratory

Scanning electronic microscopy

Tensile tests
EN ISO 10319

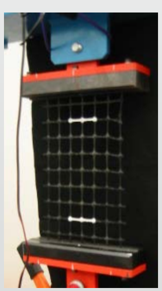
Creep & creep rupture tests
EN ISO 13431

Pullout tests
EN 13738

Inclined plane shear tests
EN ISO 12957-2







Creep rupture tests – long-term behaviour

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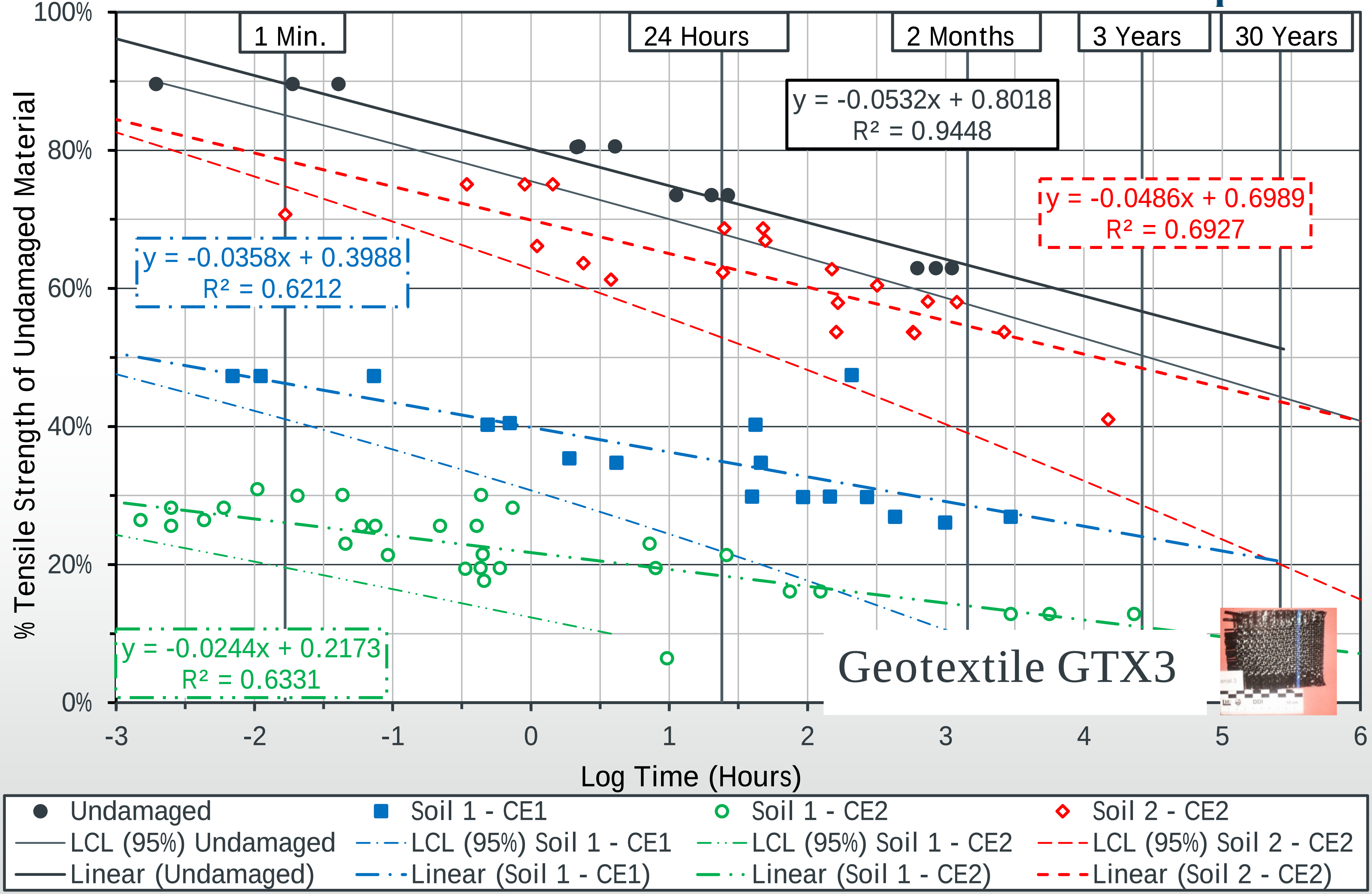

Creep rupture tests – long-term behaviour

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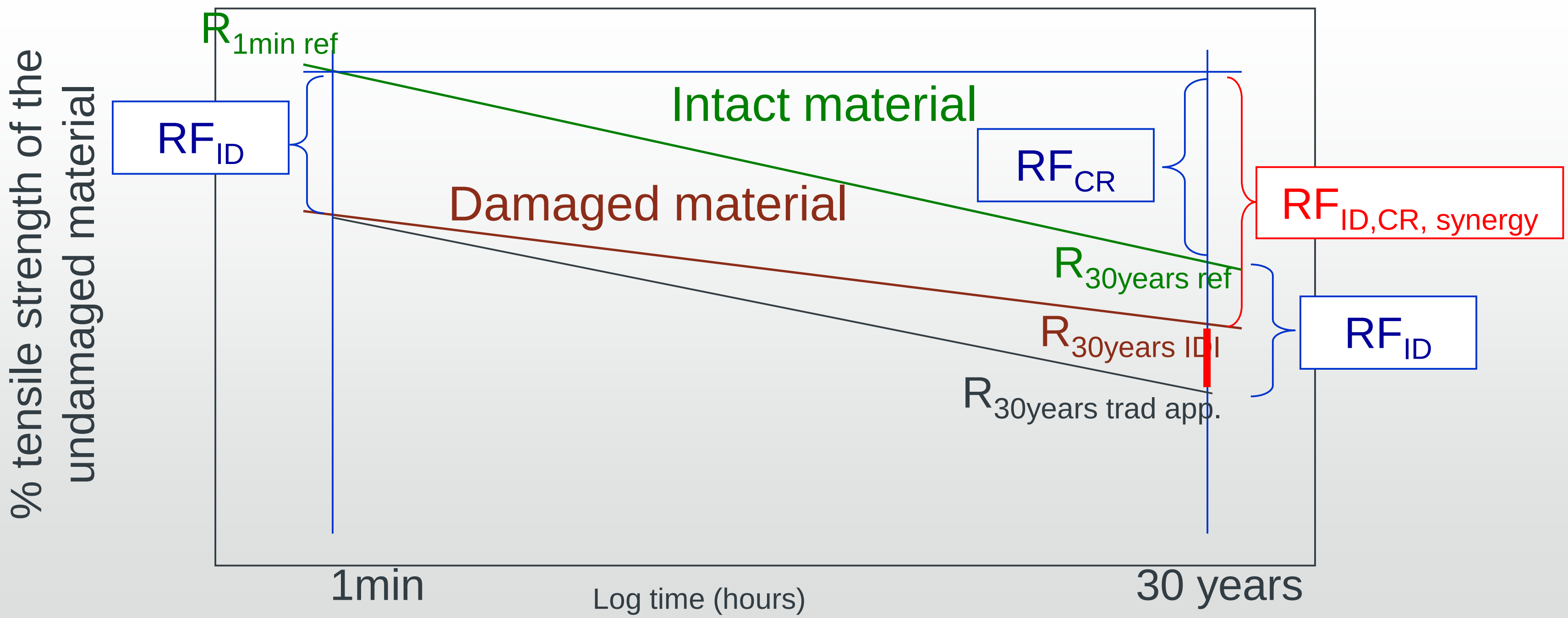
Traditional approach

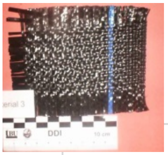
$$RF_{ID,\,CR\ \mathrm{trad}} = RF_{ID} \times RF_{CR} = \frac{R_{t\ ref}}{R_{t\ IDI}} \times \frac{R_{1\,\mathrm{min}\ ref}}{R_{30\ \mathrm{years}\ ref}}$$

Synergy

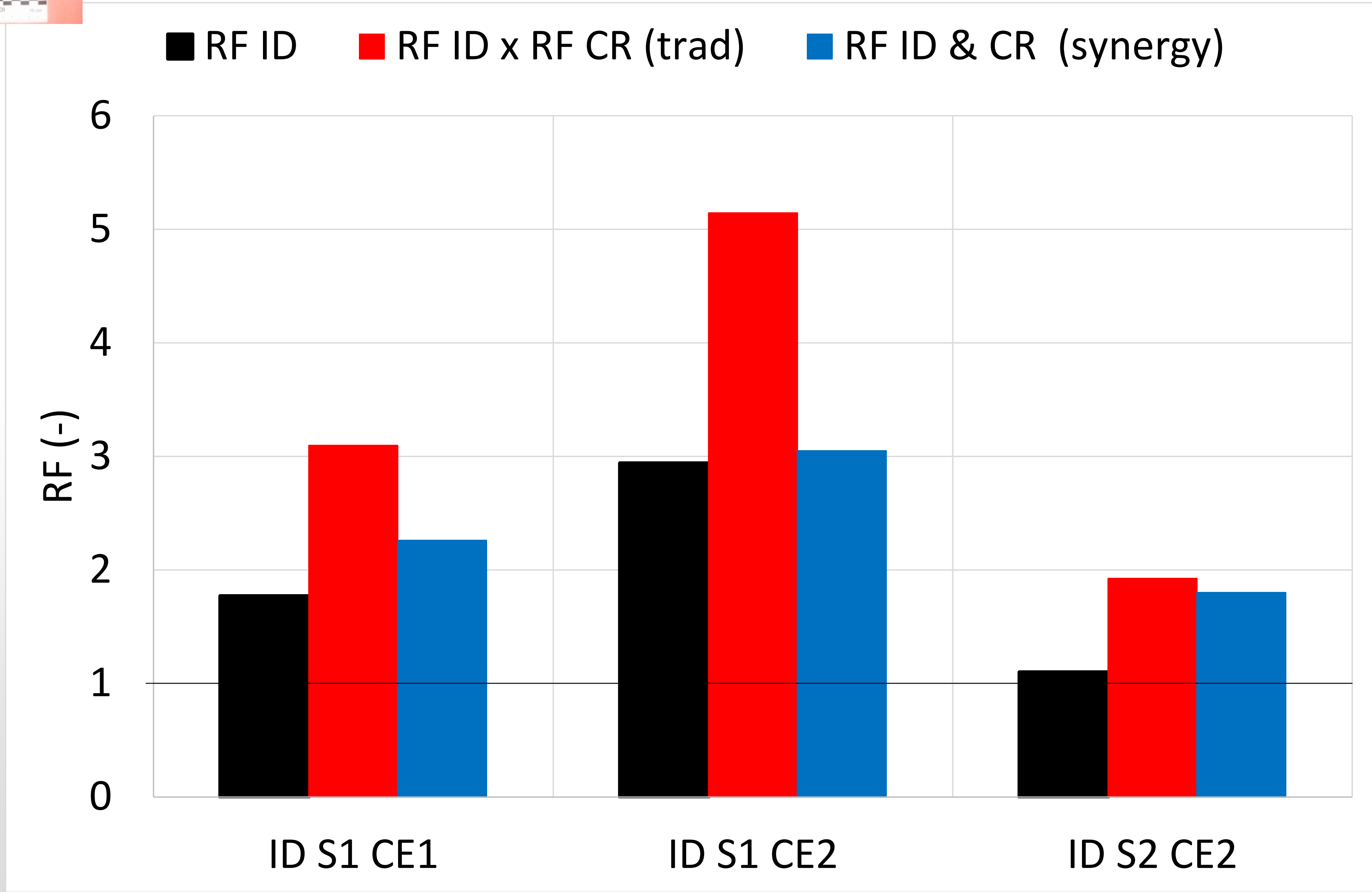
$$RF_{\mathrm{ID},\,CR\ \mathrm{synergy}} = RF_{\mathrm{ID}\ \&\ CR} = \frac{R_{1\,\mathrm{min}\ ref}}{R_{30\ \mathrm{years\ ID}}}$$



Creep rupture tests – reduction factors

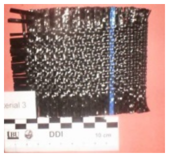


Geotextile GTX3

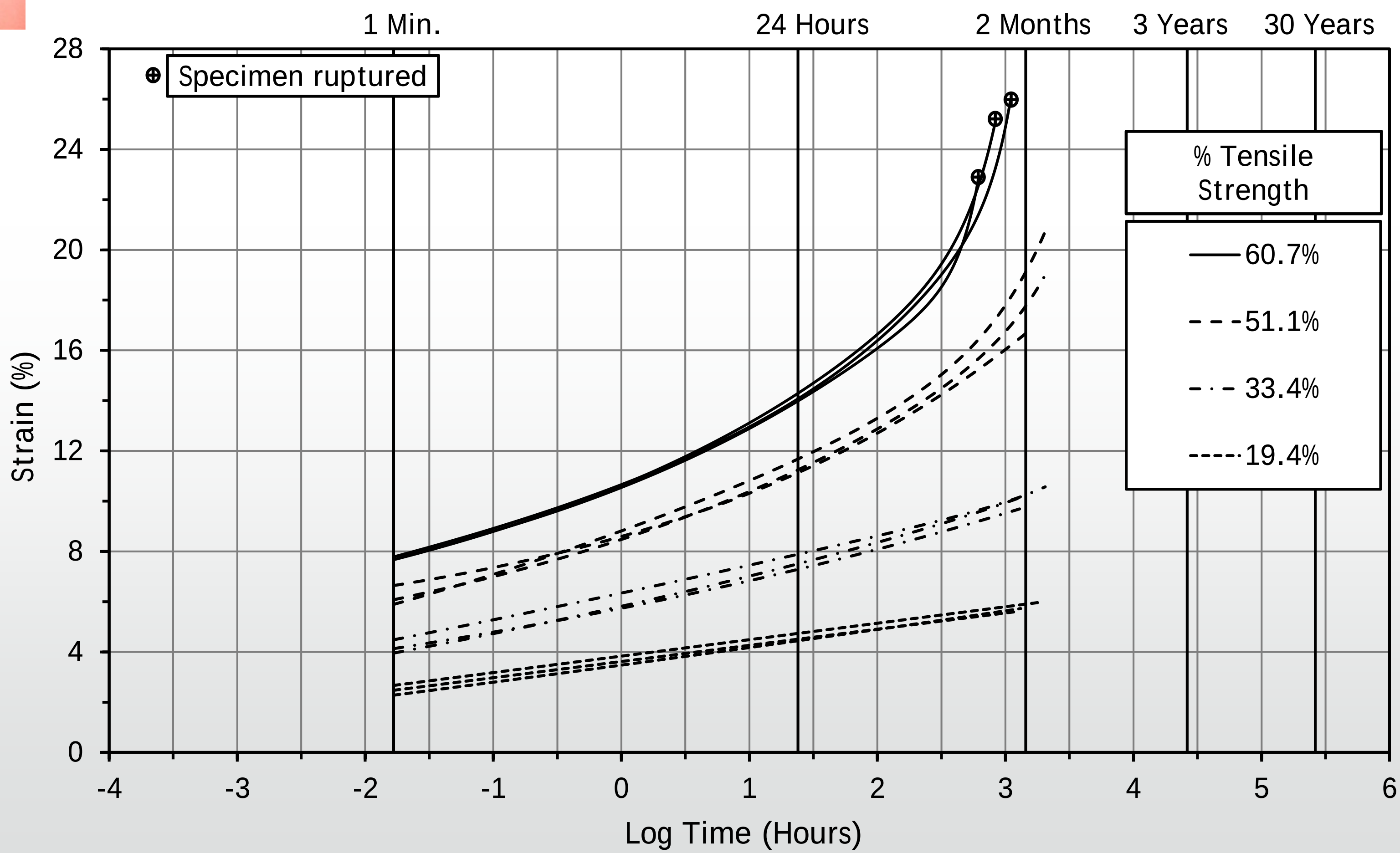


Creep tests

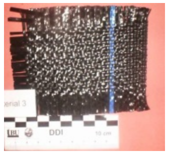
Undamaged



Geotextile GTX3



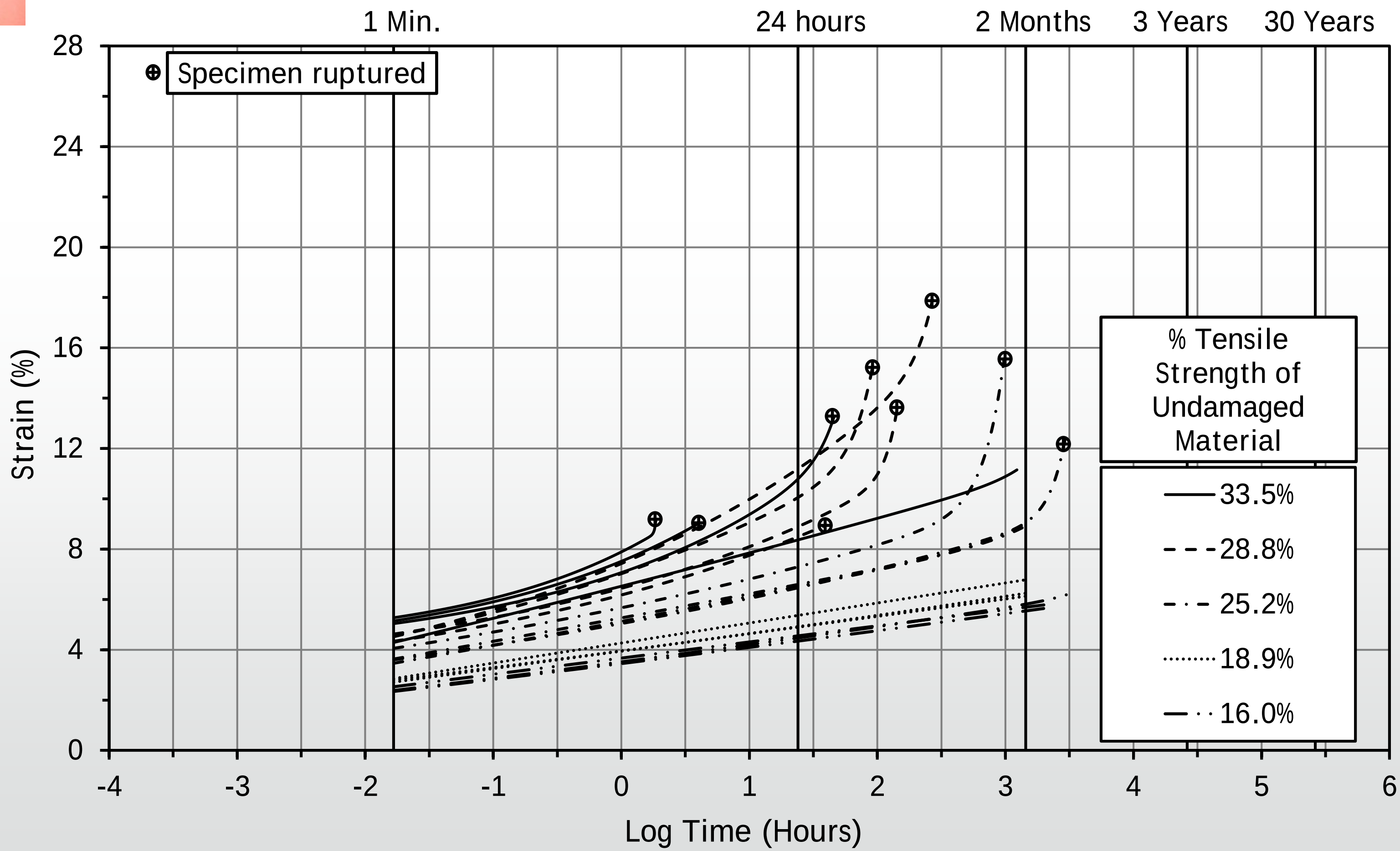
Creep tests



Geotextile GTX3

Field damaged

S1 CE1



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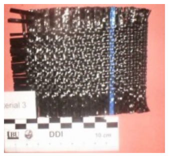
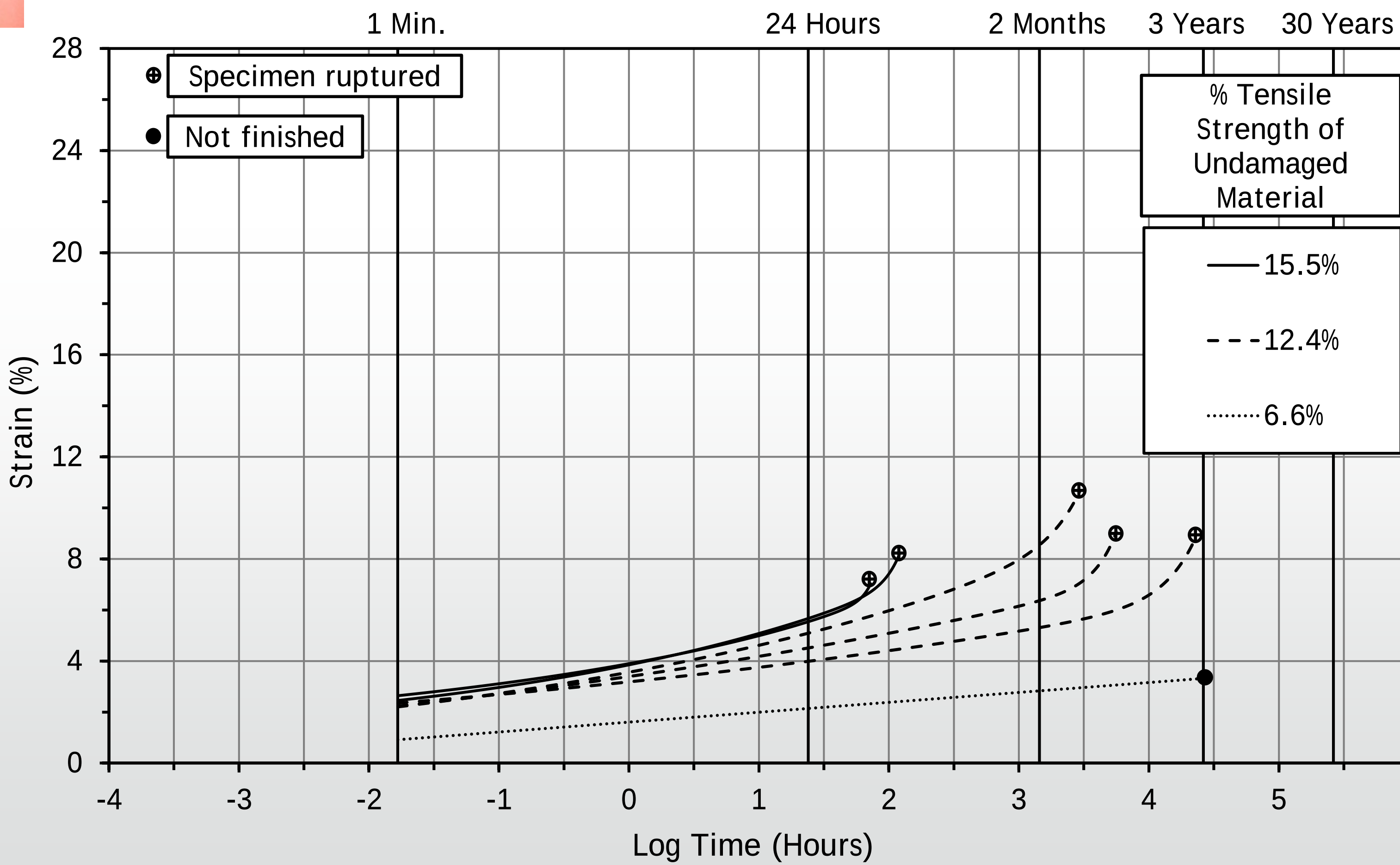
Creep tests

Field damaged

S1 CE2



Geotextile GTX3



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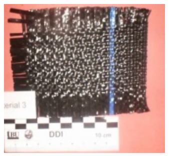
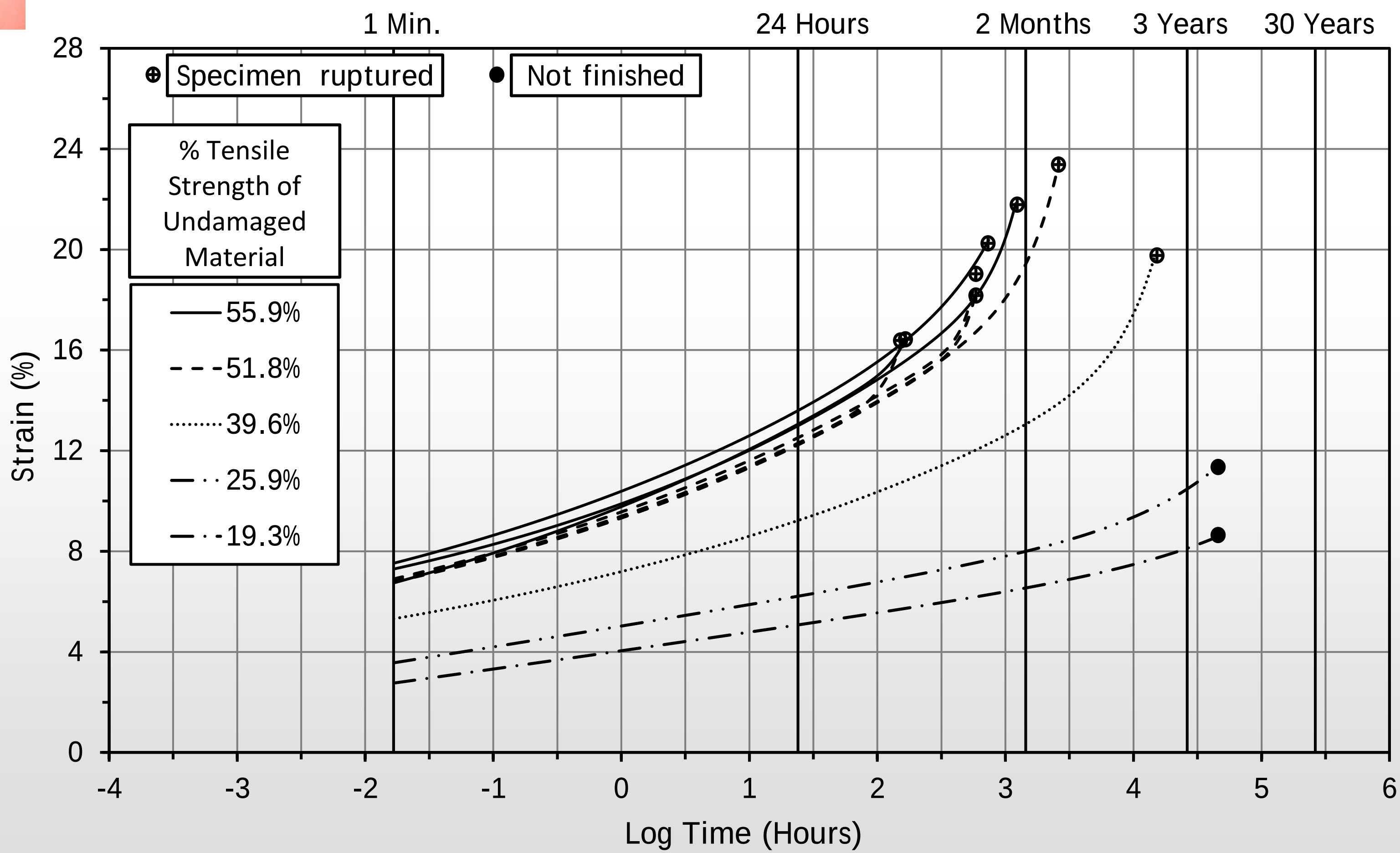
Creep tests



Geotextile GTX3

Field damaged

S2 CE2



Geosynthetics

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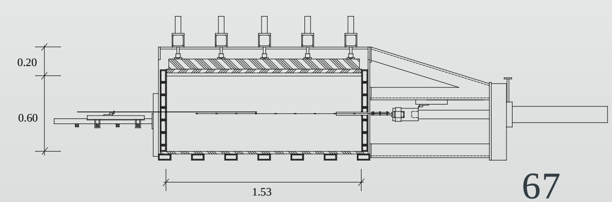
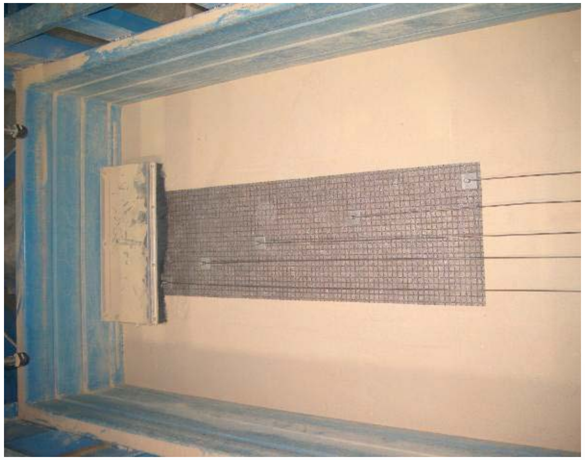
- Intact material (reference)
- Installation damage (damaged)
  - Field
  - Laboratory

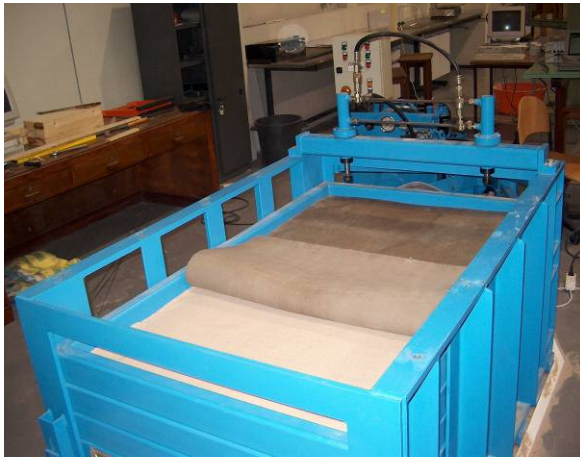
Tests:

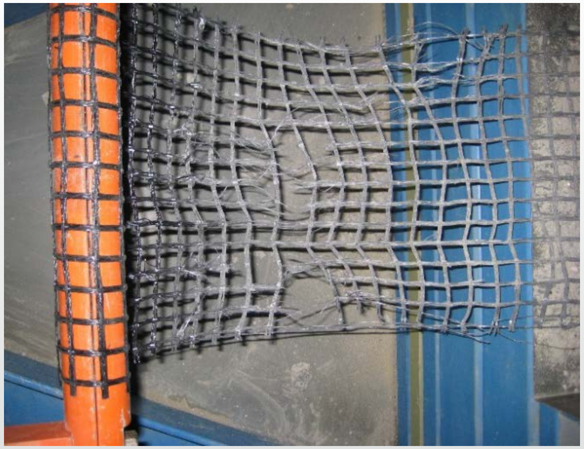
- Tensile tests EN ISO 10319
- Creep & creep rupture tests EN ISO 13431
- Scanning electronic microscopy
- Pullout tests EN 13738
- Inclined plane shear tests EN ISO 12957-2



Pullout tests







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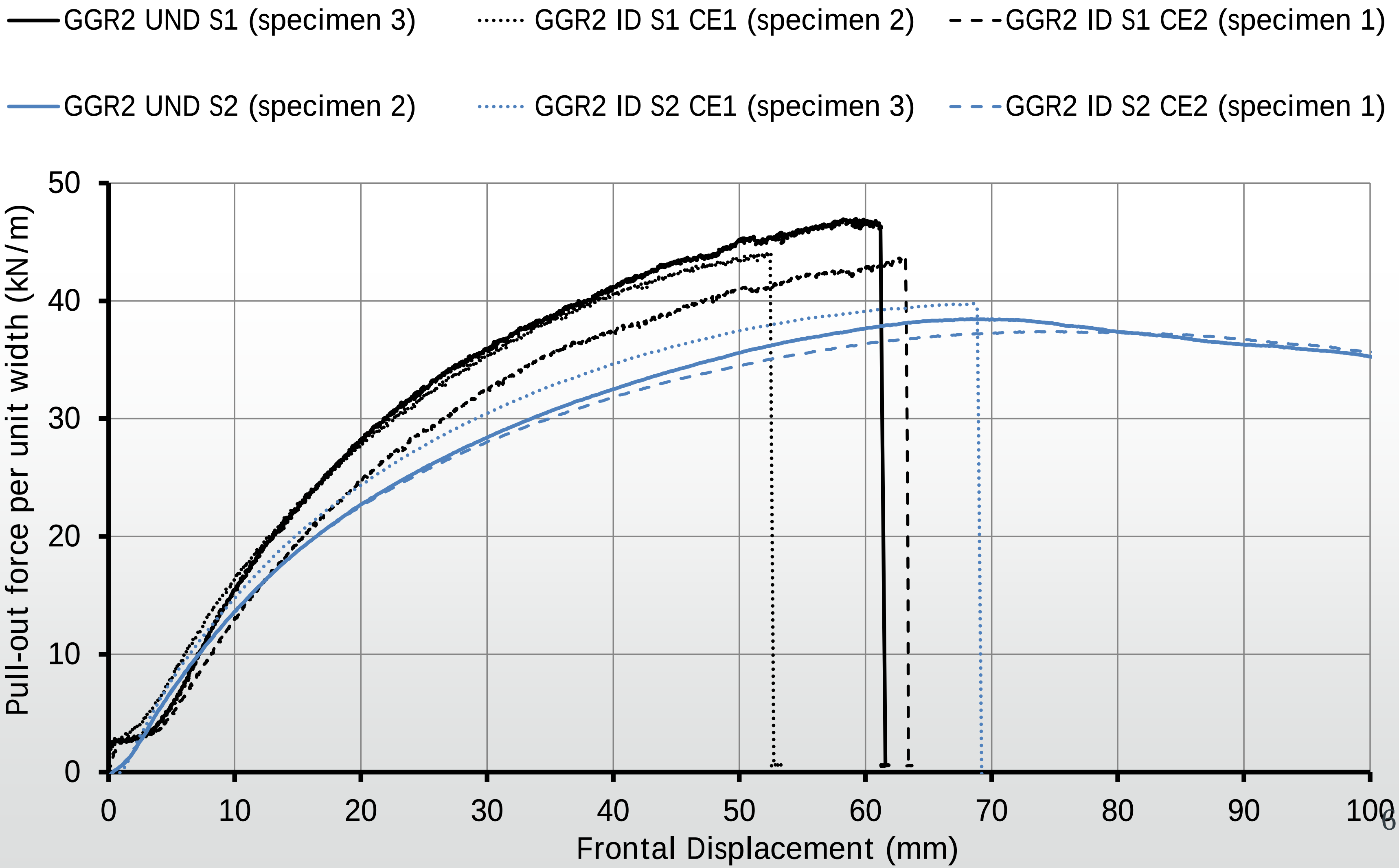
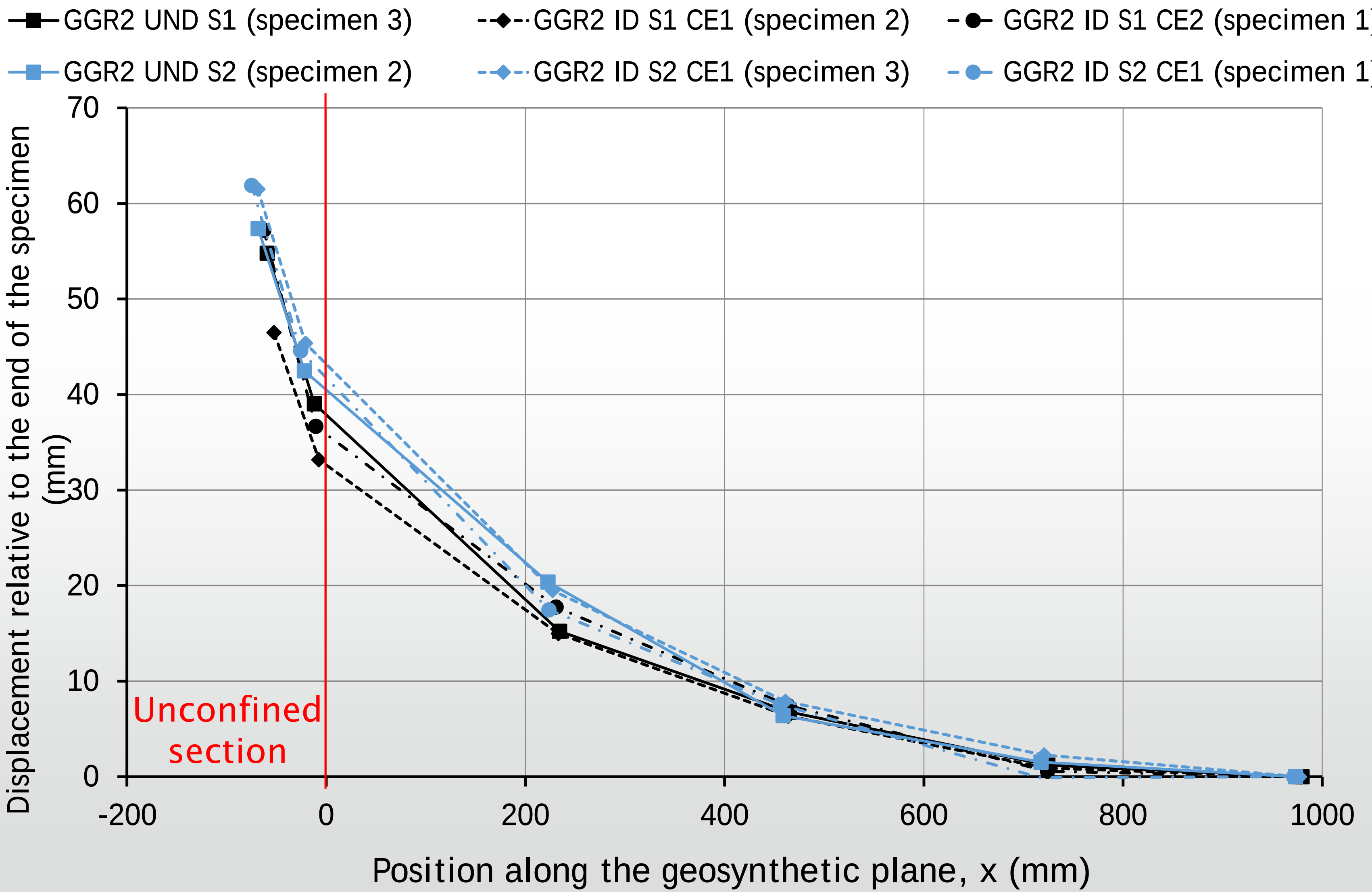
Pullout tests

Geogrid
GGe1

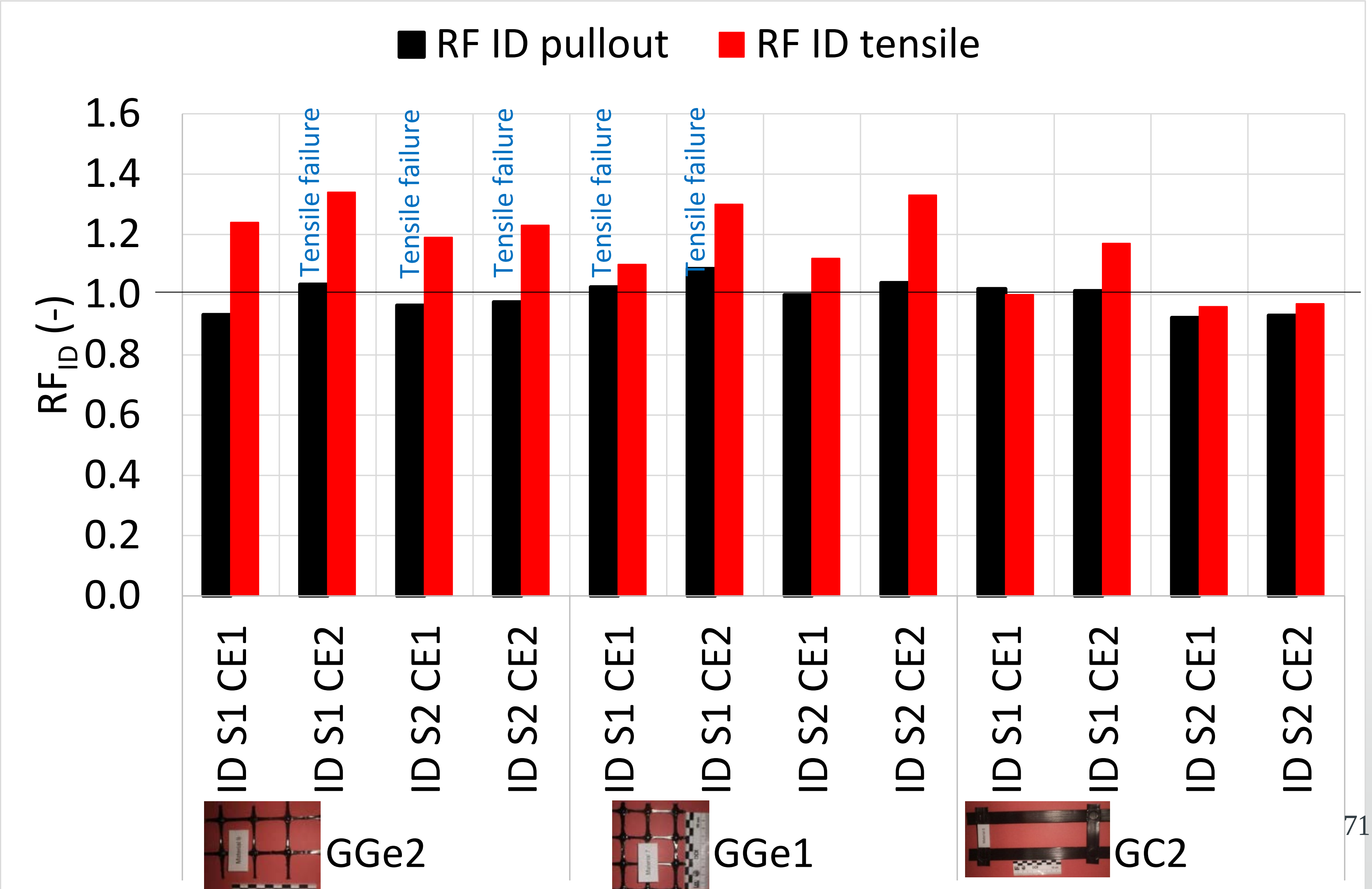


Pullout tests

Geogrid GGe1



Pullout tests – reduction factor



Part 4.1

ADDITIONAL TEST PROGRAMMES

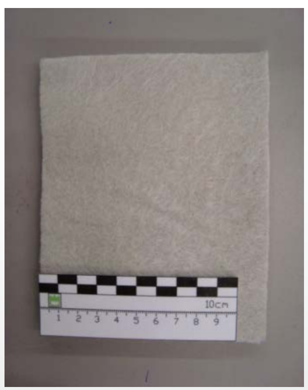
Analysis was / is being extended

- Other geosynthetics
  - Associations of geosynthetics
- Other agents and synergy between them
  - Abrasion
  - Compressive creep
  - Degradation related

Other geosynthetics and combinations

Non-woven geotextiles

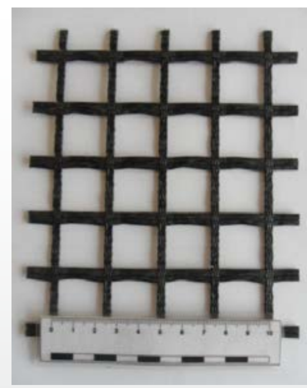




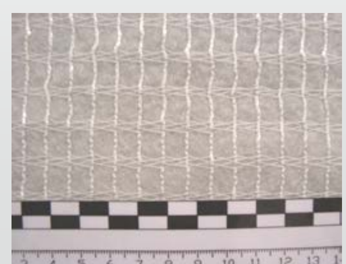
Drainage geocomposites

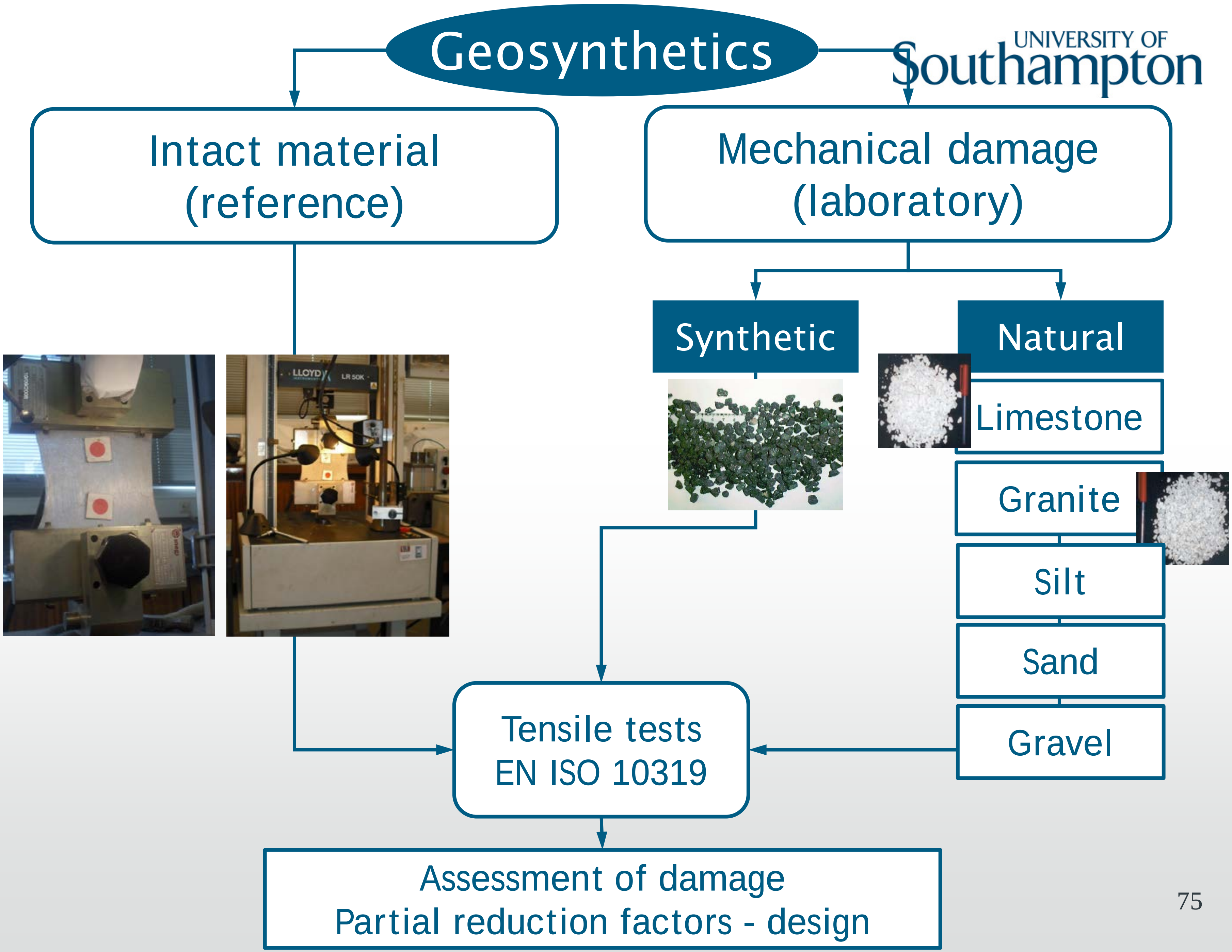

Geomembranes

Geogrids

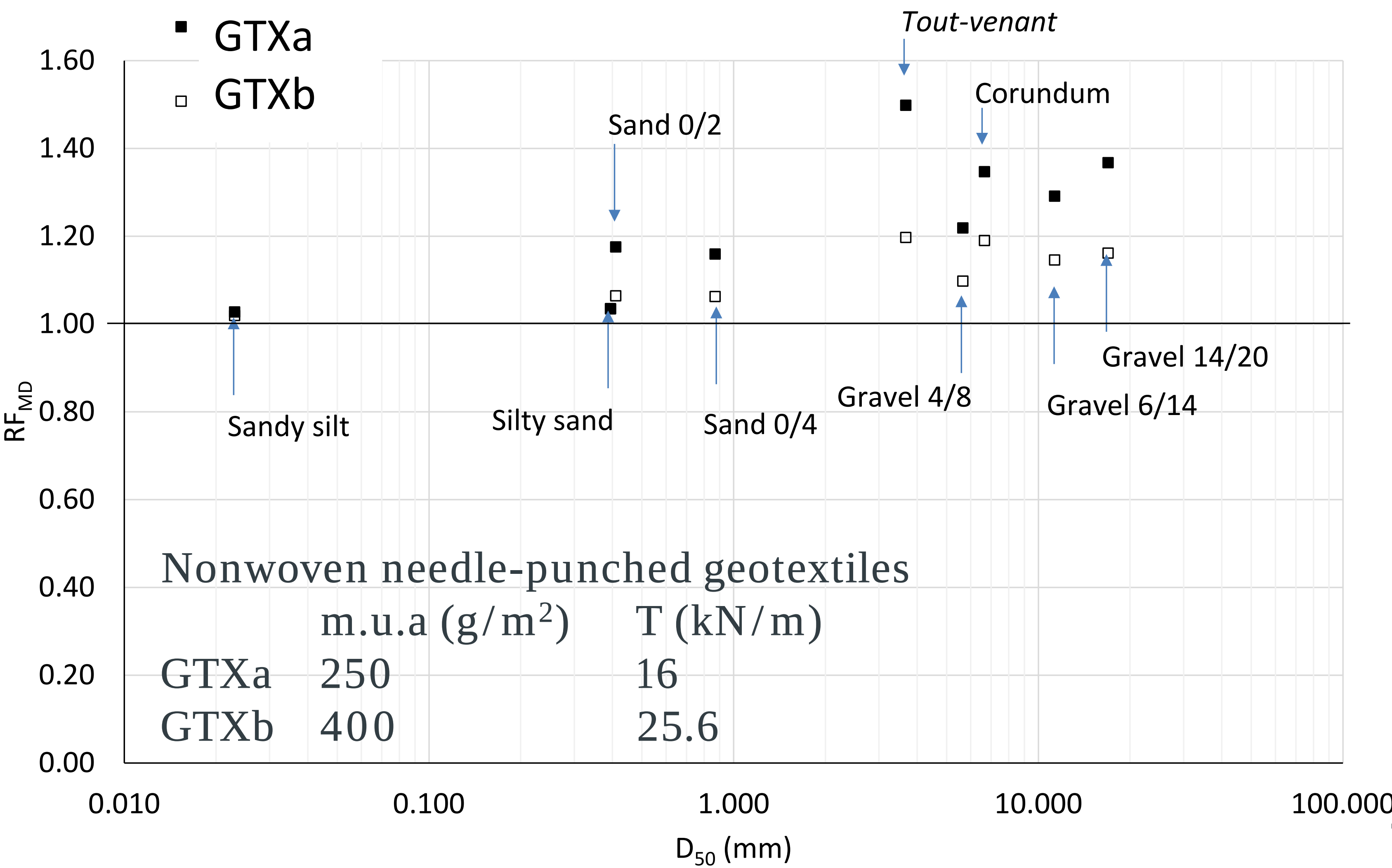


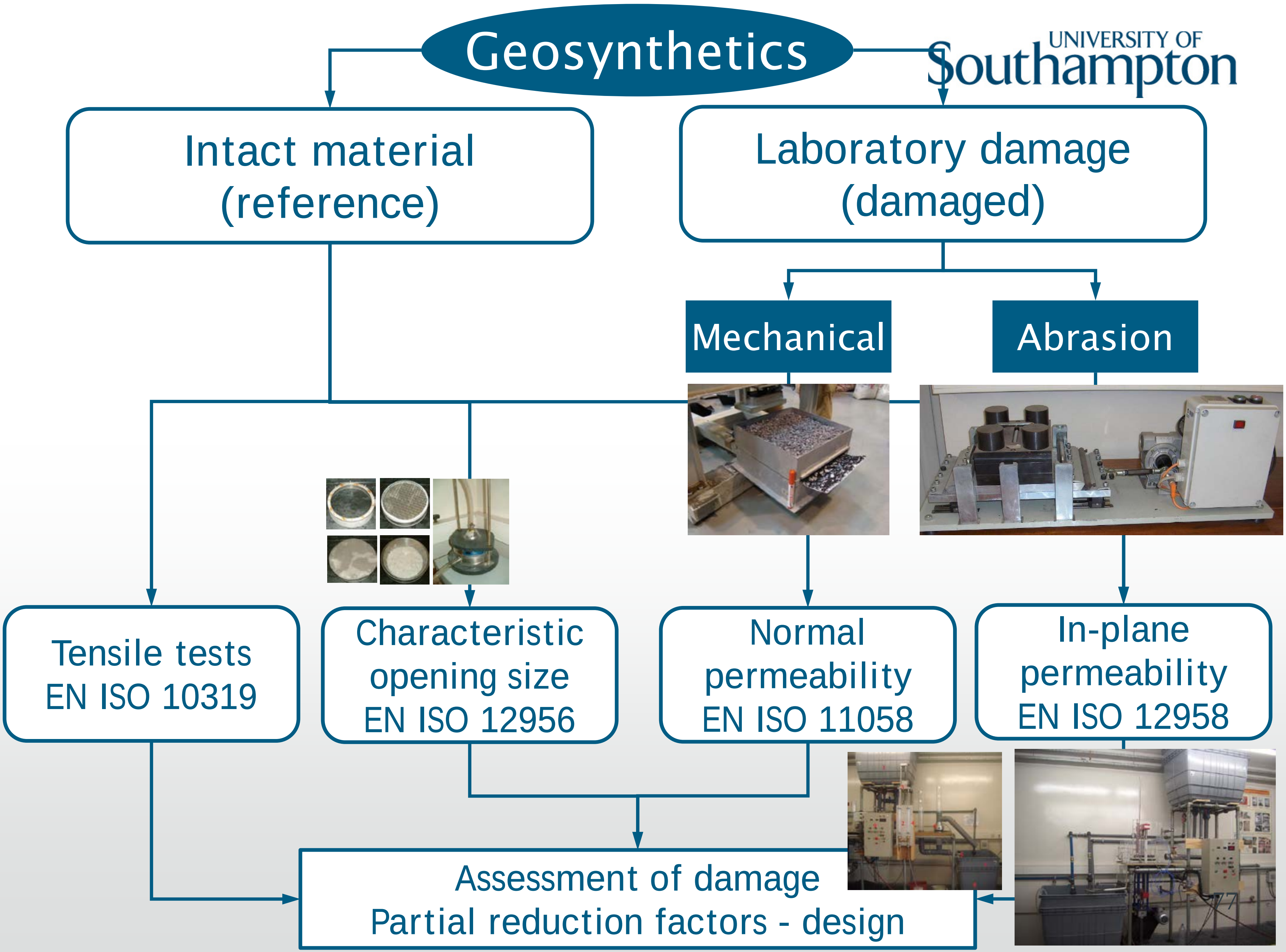

Reinforcement geocomposites

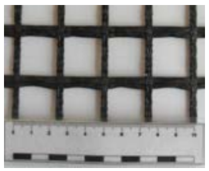
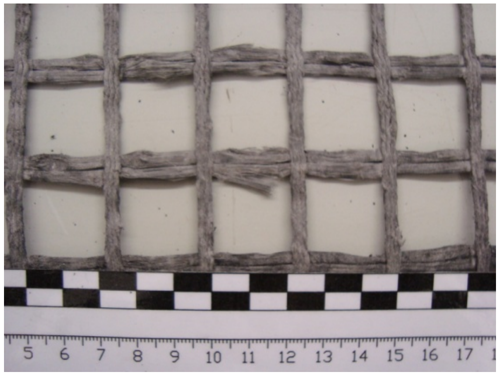
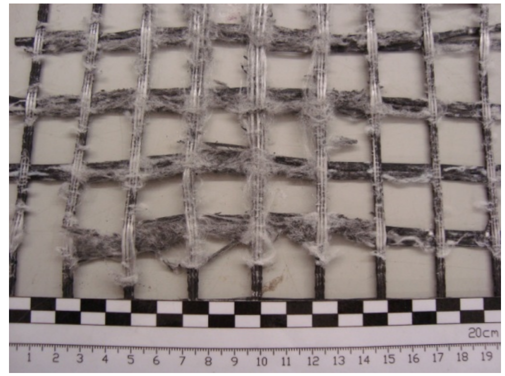
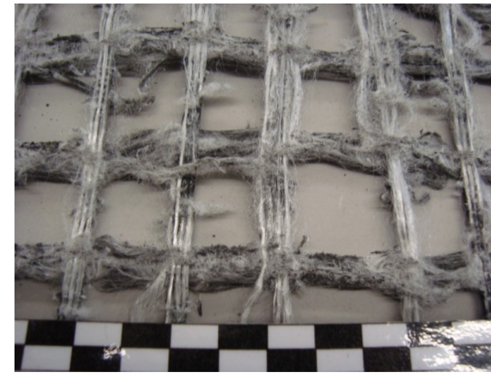
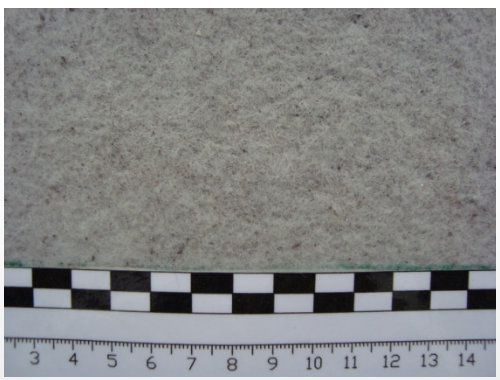
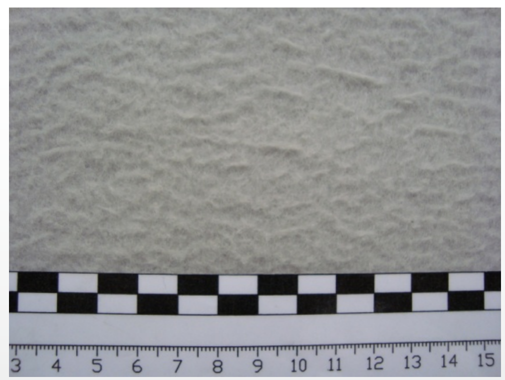
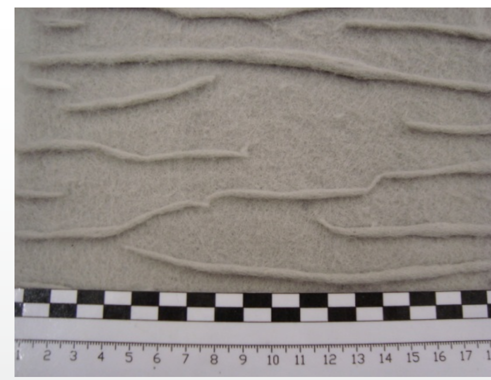
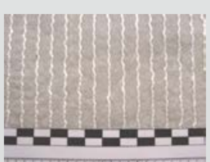
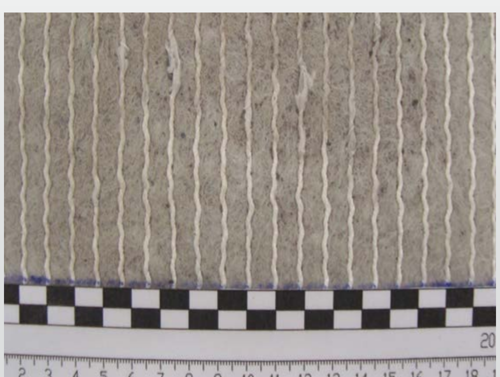
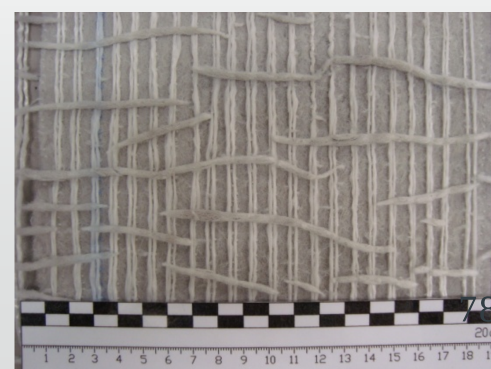




Geosynthetics
Intact material
(reference)
Mechanical damage
(laboratory)
Synthetic
Natural
Limestone
Granite
Silt
Sand
Gravel
Tensile tests
EN ISO 10319
Assessment of damage
Partial reduction factors - design

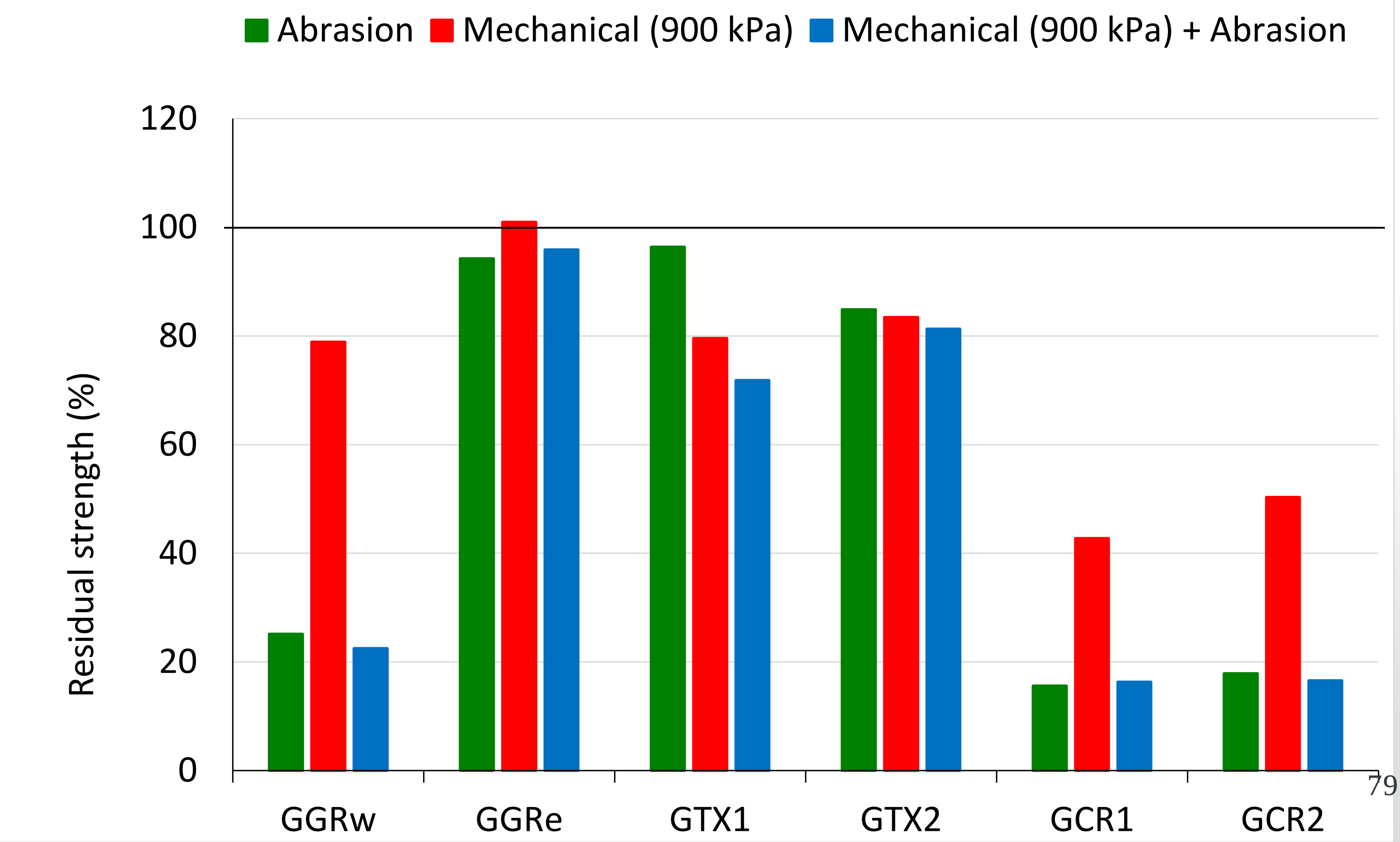
Reduction factor – laboratory test (soil)



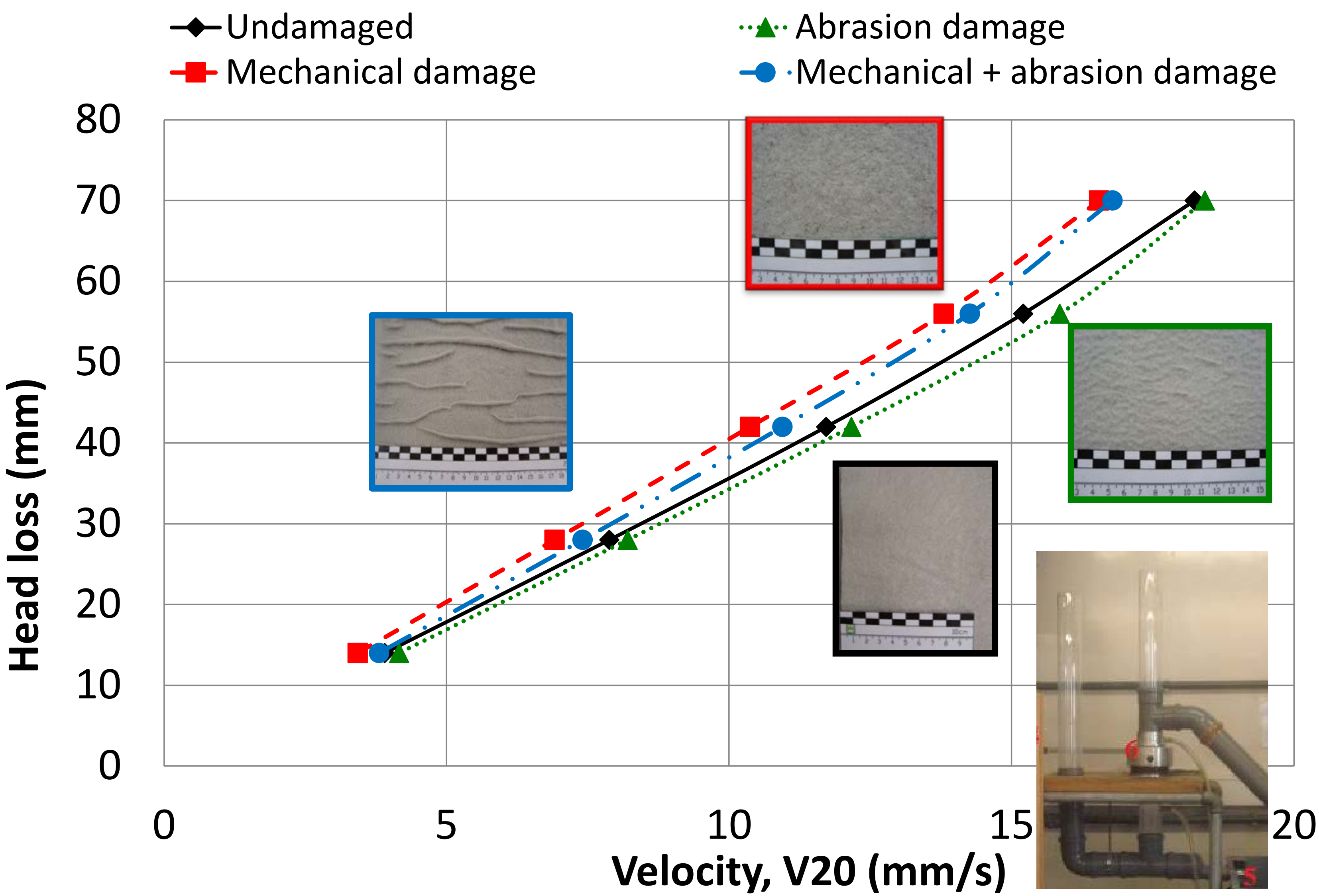

Geosynthetics
UNIVERSITY OF Southampton
Intact material (reference)
Laboratory damage (damaged)
Mechanical
Abrasion
Tensile tests EN ISO 10319
Characteristic opening size EN ISO 12956
Normal permeability EN ISO 11058
In-plane permeability EN ISO 12958
Assessment of damage
Partial reduction factors - design

	Mechanical damage	Abrasion damage	Mechanical + Abrasion
GGRw 			
GTX2 			
GCR2 			

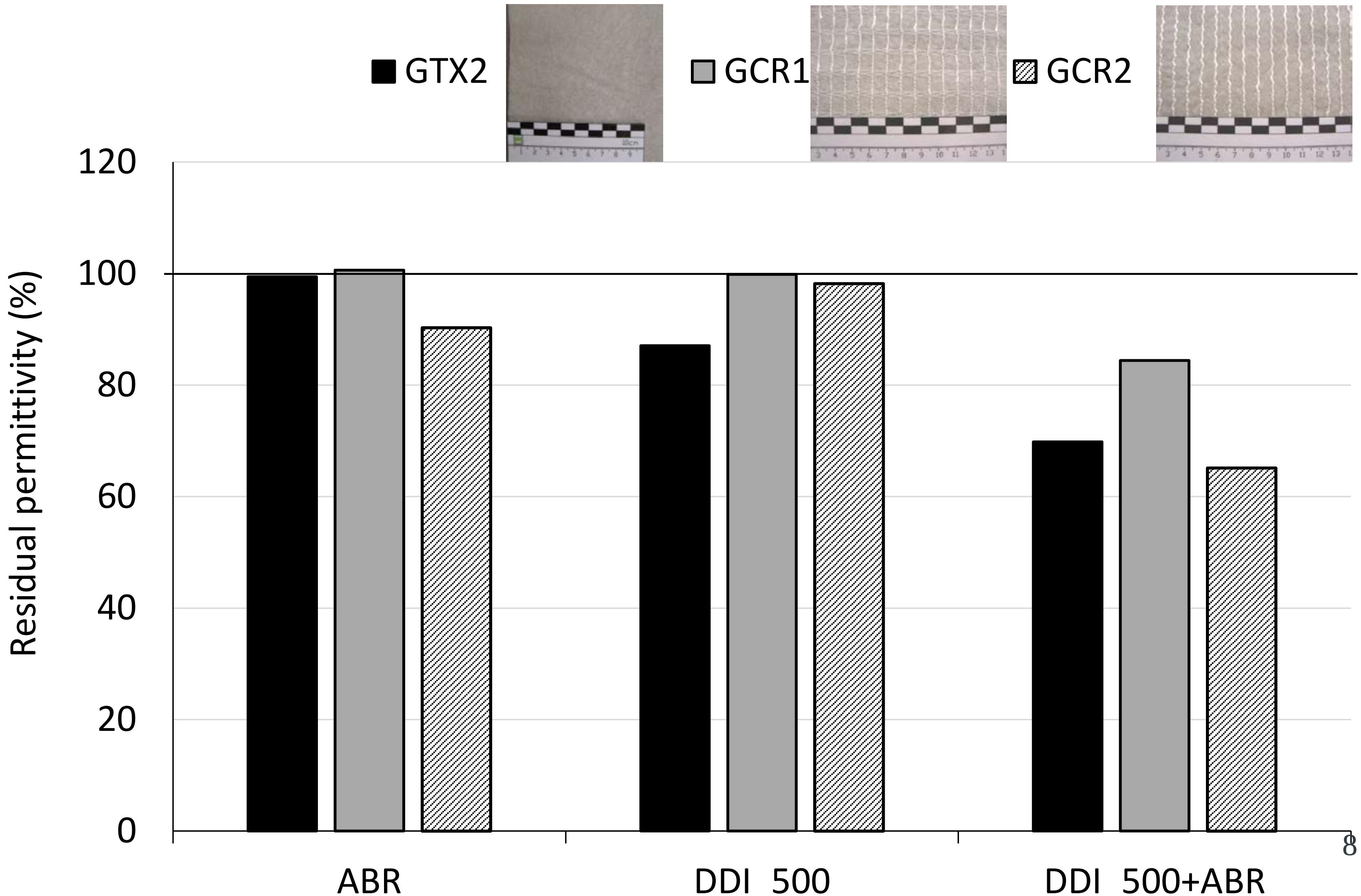
Tensile strength – residual values



Normal permeability



Normal permeability – residual values



Part 5

RECOMMENDATIONS AND SUMMARY

Laboratory damage test

- Laboratory damage test
  - Aggregate used affects the results
    - Fragmentation
    - Cutting faces
  - Correlation with field conditions
  - Scale, size of box and load plate

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Recommendations and summary

- Field simulations (≠ field trials)
  - BS 8006-1. Annex D
  - NorGeoSpec 2012
  - ASTM D 5818-11
    - Using project specific materials and procedures
    - Or generally accepted and representative materials and procedures

Pullout response after installation damage

- Coefficient of interaction was affected differently by installation, depending on
    - Geosynthetic
    - Soil

- Installation damage reduction factors
    – Results from tensile tests overestimate those from pullout tests

- Compaction under wet conditions
    – Layer of dust and dirt – reduced skin friction

Hydraulic properties

- Apparently contradicting changes in
  - Characteristic opening size
  - Permittivity

- Most likely due to the different test setup and conditions
- Cumulative effects of mechanical damage and abrasion seem to important - synergy

Specifications

- Include information on installation and construction procedures
- Define relevant properties – NOT mass per unit area
- Include a set of tests to confirm if the products delivered on site meet the specifications

Acknowledgements

- Portuguese Roads Institution (*Instituto de Estradas de Portugal*)
- FCT, Research Project PTDC/ECM/099087/2008
- COMPETE, Research Project FCOMP-01-0124-FEDER-009724

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Publications with additional information

Pinho-Lopes, M., Paula, A.M. and Lopes, M.L. (2015) Pull-out response of geogrids after installation. *Geosynthetics International*, 22(5), 339–354.

Pinho-Lopes, M. and Lopes, M.L. (2015) Synergisms between laboratory mechanical and abrasion damage on mechanical and hydraulic properties of geosynthetics. *Transportation Geotechnics*, 4, 50-63.

Carlos, D., Carneiro, J.R., Pinho-Lopes, M. and Lopes, M.L. (2015) Effect of soil grain size distribution on the mechanical damage of nonwoven geotextiles under repeated loading. *International Journal of Geosynthetics and Ground Engineering*, 1 (1), 1-7.

Pinho-Lopes, M. and Lopes, M.L. (2014) Tensile properties of geosynthetics after installation damage. *Environmental Geotechnics*, 1 (3), 161-178.

Rosete, A., Mendonca Lopes, P., Pinho-Lopes, M. and Lopes, M.L. (2013) Tensile and hydraulic properties of geosynthetics after mechanical damage and abrasion laboratory tests. *Geosynthetics International*, 20 (5), 358-374.

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Installation damage of geosynthetics and consequences for the design

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