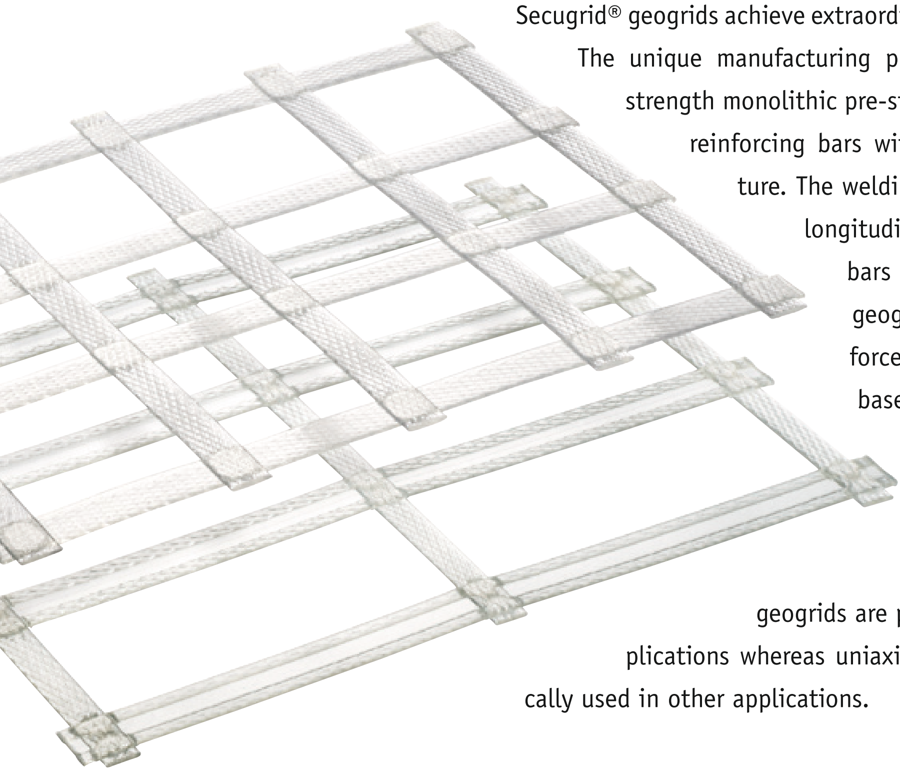
Building on subsoils with low bearing capacity:

BASE COURSE REINFORCEMENT with GEOGRIDS

NAUE



Secugrid® geogrids achieve extraordinary high strengths at low strains. The unique manufacturing process produces structured, high strength monolithic pre-stressed polypropylene or polyester reinforcing bars with a continuous molecular structure. The welding process that strongly joins the longitudinal and transverse reinforcement bars creates a firm, inherently rigid geogrid for use in base course reinforcement. Typical applications include base course reinforcement, reinforced slopes and retaining walls and earthen dam foundations, bridging of mining voids and sinkholes. Biaxial Secugrid® Q geogrids are preferably used in base course applications whereas uniaxial Secugrid® R geogrids are typically used in other applications.

Combigrid® is a composite reinforcement solution that embeds a Secutex® nonwoven geotextile within a Secugrid® geogrid. This provides reinforcement, filtration, separation and drainage in a single composite product. The geogrid-nonwoven geotextile geocomposite is primarily used on soft soils with low bearing capacity, such as with unbound, dynamically loaded layers that require filtration and separation support.

TABLE OF CONTENTS

TOPIC **PAGE**

TOPIC #1: Geogrid Effectiveness 4

TOPIC #2: Interlocking and Friction 5

TOPIC #3: Tensile Strength 6

TOPIC #4: Extensional Stiffness 7

TOPIC #5: Radial Effect 8

TOPIC #6: Construction Strain 9

TOPIC #7: Torsional Rigidity 10

TOPIC #8: Robustness 11

TOPIC #9: Bond Efficiency 12

TOPIC #10: Bearing Capacity Design (E_{V2}-method) 13

TOPIC #11: Serviceability Design (Rut Deformation Method) 14

References 15

TOPIC #1:
Geogrid Effectiveness

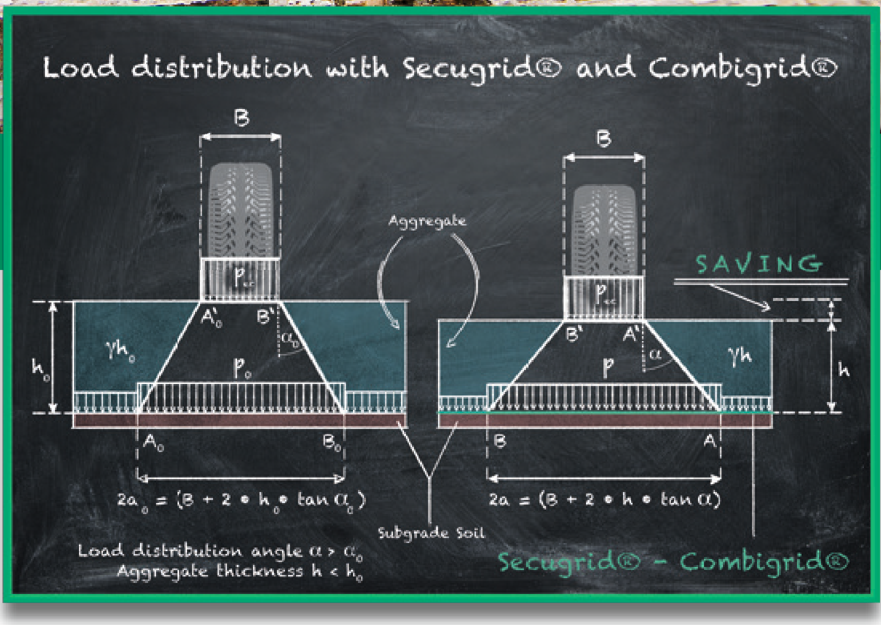


Figure 1
Saving of granular material in the base course by using Secugrid® and Combigrid® reinforcement products

Geogrids reinforce granular layers

Basic Information

- A geogrid absorbs the loads that are transferred into a granular layer (e.g. base/ sub-base course) via interlocking and friction (interaction with the fill material, see Topic 2). This is similar to how rebar and steel reinforcement improve concrete.
- An open geogrid structure enables this exceptional load transfer.
- In this way, the load distribution within a granular layer increases while decreasing the transfer of stresses towards the subsoil.
- Geogrid reinforcement inside a granular base course mitigates the effect of differential settlements.

The use of Secugrid® and Combigrid® geogrids has the following effects:

- Reduction/mitigation of differential settlements
- Reduction of the base course thickness combined with cost savings
- Reduction of rut formation
- Lateral restraint of the granular structure
- Stiffening of the granular layer (increase of elastic modulus)
- Bridging of locally occurring soft spots (inhomogeneous subsoils)
- Increase of serviceability and service life
- Considerable CO_2 reduction compared to conventional construction methods

The positive effectiveness of geogrids is enabled through different technical parameters, which are described in the following sections.

Figure 2
Secugrid® geogrid reinforced stone columns carry a nearly 2 ton heavy delivery van during a live experiment (see http://www.naue.com/en/naue-tv/geogrid-experiment.html)

TOPIC #2:
Interlocking and Friction

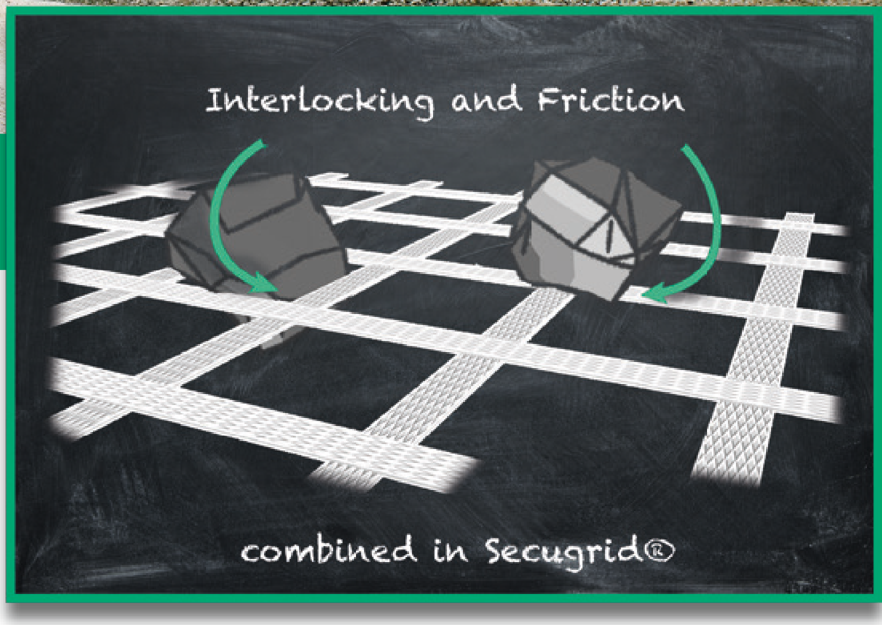


Figure 3 Schematic illustration showing interlocking (soil particle between bars) and friction (soil particle on top of the bar)

Interaction of geogrid and soil

Basic Information

- The interaction of interlocking and friction between geogrids and fill is the decisive factor in achieving effective and optimal reinforcement.
- Interlocking is the anchoring of aggregate particles within geogrid apertures.
- Friction is the interaction between granular particles and the geogrid surface.

Effects

- Interlocking and the frictional characteristics between a geogrid and fill material transfer stresses into the reinforcement, which redistributes loads, thus strengthening the overall system.
- Geogrids lock the aggregate in place within a base course. This reduces the lateral deformation of the fill.
- A high torsional rigidity (Topic 7) in a geogrid optimises the interlocking effect.
- The embossed bars of Secugrid® provide a better frictional bond with soil than do products that do not have surface texturing. This is true even with small displacements.
- An indicator of the interaction efficiency between a reinforcement product and fill material is the frictional coefficient (combination of interlocking and friction).

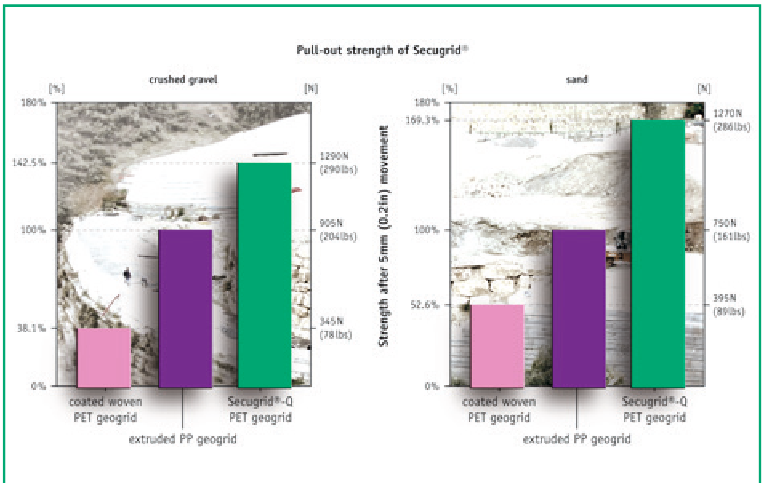


Figure 4 Comparison of pull-out behaviour of different geogrids installed in gravel and sand

Advantages of Secugrid®/Combigrid®

- The geometry and surface structure of Secugrid®/Combigrid® bars optimises the interaction between interlocking and frictional characteristics.
- The stiff bars (Topics 4, 6, and 7) and high surface roughness enable a strong bond with a wide range of fills and granulometric distributions (see Figure 3).
- The high torsional rigidity of Secugrid® (Topic 7) efficiently transfers stresses from the fill into the grid structure. Shear deformations in the fill material are reduced, including with small deformations.
- Texturing is provided on both sides of the Secugrid®/Combigrid® bars to activate higher frictional resistance and improve the load transfer.
- When using Secugrid®/Combigrid® geogrids, the earth pressure resistance, which develops in front of the bars, is optimally transferred via the efficiency of the junctions (Topic 9).

TOPIC #3:
Tensile Strength

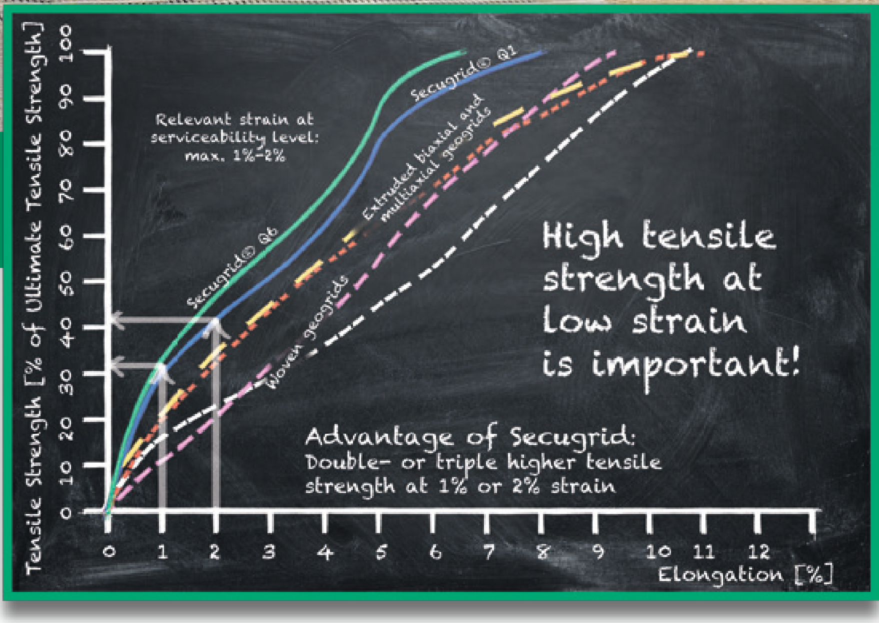


Figure 6
Exemplary stress-strain curves for Secugrid®, Combigrid® and other geogrids

Immediate Stress absorption offers safe construction

Basic Information

- Granular layers are weak in absorbing tensile forces.
- Loads which are transferred into the geogrid structure via interlocking and friction are distributed by the reinforcement via the tensile elements (bars) and the junctions.
- Based on the applied load, the geogrid must absorb the maximum stress by providing sufficient tensile strength (expressed in kN/m).
- The tensile strength of the geogrid reinforcement must increase as subsoil bearing capacity decreases.
- The effectiveness under serviceability conditions must be checked by estimating the strain at the relevant stress level (See Topic 4, Extensional Stiffness).

Effects

- Applied stresses are absorbed and transferred via the geogrid reinforcement. Thus, excessive stresses in the fill material and subsoil (base failure) are avoided.
- Absorbing greater tensile forces under typical serviceability conditions (0% to 2% elongation) helps limit deformations in the base course (Topic 4), especially on soft soils.
- When installed in base courses, the reinforcement must be able to mobilise tensile forces in all directions (multi-axial), in order to be able to distribute the applied loads efficiently (see Topic 5, Radial Stiffness).

Figure 5
Large-scale installation of a Secugrid® reinforced base course

Advantages of Secugrid®/Combigrid®

- ✓ Geogrids with varying tensile strength, which can optimally be adapted to the project specific conditions.
- ✓ High tensile strength at low strain.
- ✓ Small deformations, caused by comparably high tensile strength at strain levels, which are within the service load range (0% - 2%).

TOPIC #4:
Extensional Stiffness

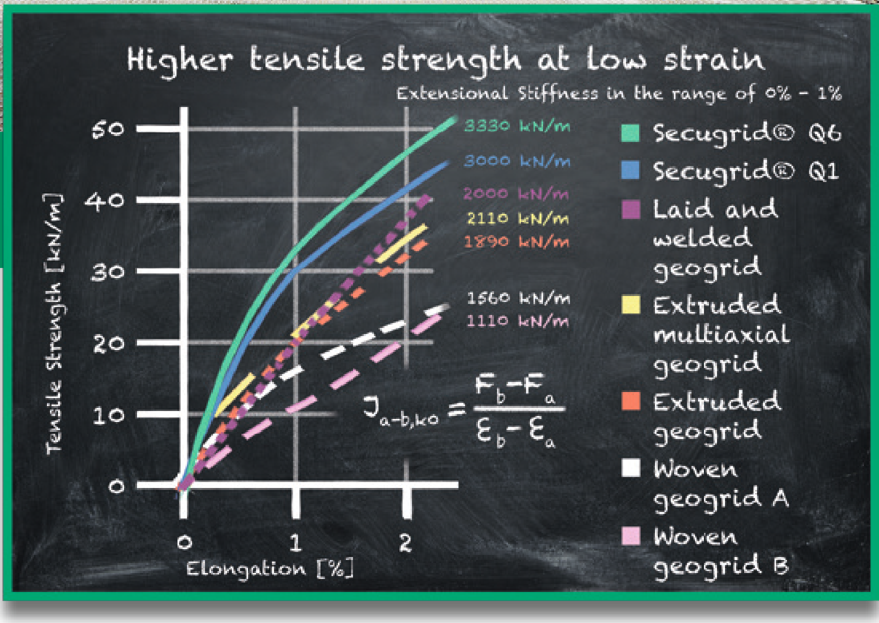


Figure 8 Exemplary stress-strain curves for Secugrid®, Combigrid® and other geogrids in the strain range of between 0% to 2% at a comparable ultimate tensile strength

Effective reinforcement effect due to high force absorption at a low strain

Basic Information

- The extensional stiffness or secant modulus (J) of a geosynthetic reinforcement can be specified as a measure for the stress-strain-behaviour of the reinforcement. The short-term extensional stiffness of a geogrid is determined on the basis of the wide-width tensile test according to EN ISO 10319 and the representative stress-strain curve:

$$J_{(a\text{-}b,k0)} = \frac{F_b - F_a}{\varepsilon_b - \varepsilon_a}$$

with:

$J_{(a\text{-}b,k0)}$ characteristic short-term extensional stiffness for the range of ε_a bis ε_b [kN/m],
F Tensile Strength at a given strain ε [kN/m],
ε given strain [-].

- One indication of the effectiveness of a reinforcement product is a steep stress-strain curve (high tensile strengths at low strains in the relevant serviceability state, mostly 0% to 2%).
- Important: a high extensional stiffness of the reinforcement must be given for all directions because the loads can be distributed radially within a base course (Topic 5).

Effects

- Exceeding the bearing capacity of the base course (e.g., heavy rut formation in an access road) destroys the bond/interaction between the granular particles (granular layers are weak in absorbing tensile forces).

Figure 7 Installation of base course aggregate on top of Secugrid®

- The service load range of a geogrid reinforcement within a granular base course layer is generally at a maximum strain level of 2%, in order to achieve an optimum interaction between the properties of the fill and the reinforcement. In this case, the reinforcement must activate a good portion of its load bearing capacity (the reinforcement effect).
- At comparable stress levels, products with low extensional stiffness exhibit greater strains than products with high extensional stiffness. This results in larger deformations and would require greater ultimate tensile strength for the product with lower extensional stiffness to show an equivalent performance to the product with high extensional stiffness.
- High extensional stiffness at low strain supports an immediate activation of the reinforcement effect at small deformations. This transfers loads more efficiently, thus considerably reducing deformation risk.

Advantages of Secugrid®/Combigrid®

- ✓ Higher extensional stiffness (especially in case of low strain levels) compared to flexible geogrids or wovens made of comparable raw materials.
- ✓ High force absorption at low strain levels as a result of pre-stressed reinforcement bars.
- ✓ Improved serviceability of the construction due to optimised load distribution.
- ✓ Mitigation of differential settlements as a result of optimum utilisation of the extensional stiffness in the Secugrid®/Combigrid® geogrid structure.

TOPIC #5:
Radial Effect

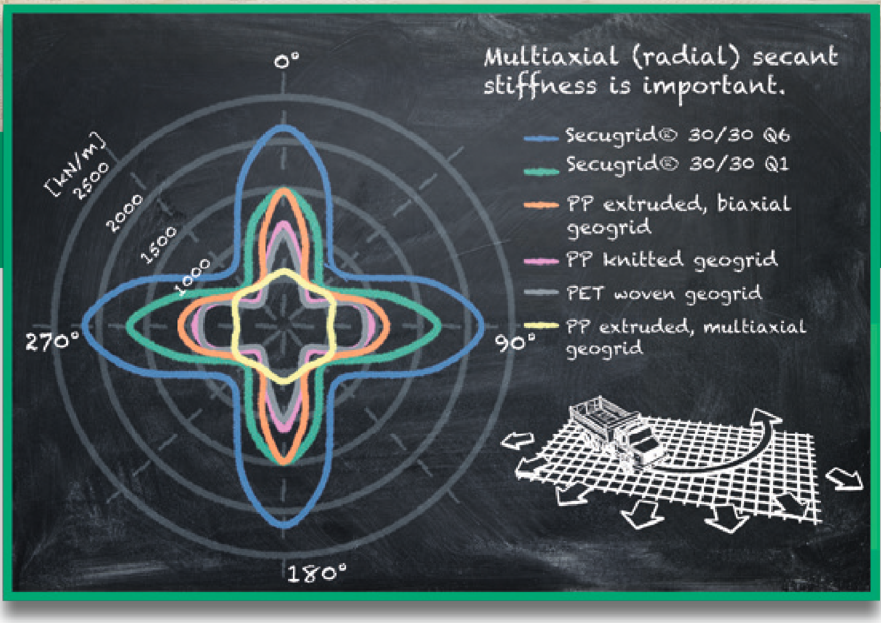


Figure 10 Radial (polar) secant modulus for Secugrid®, Combigrid® and other geogrids with comparable ultimate tensile strength at strain levels of 0.5%

Load distribution in all directions (360° effect)

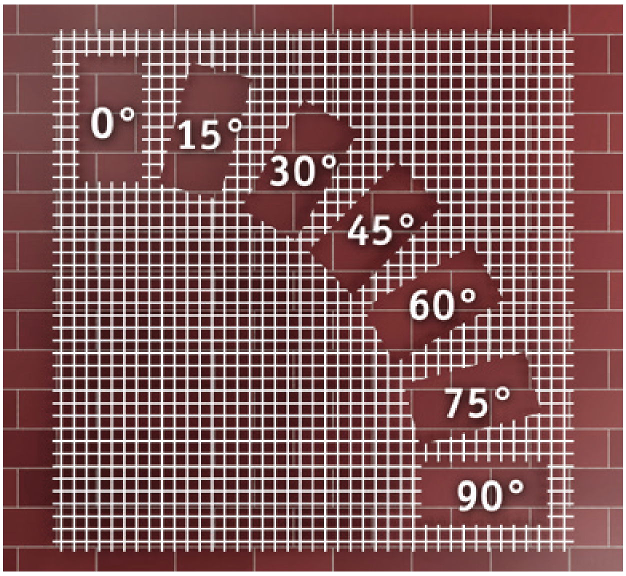
Basic Information

- The load distribution within a base course structure can be circular (radial).
- The radial effectiveness of a geogrid is linked to its ability to absorb the applied loads (e.g., wheel loads) from all directions and to transfer them effectively in all directions.
- Geogrids must absorb peak stresses in all directions. Additionally, they need to provide sufficient safety reserves in the axial direction.
- The radial extensional stiffness (Topic 4) can be used as an indicator for the radial effectiveness.

Effects

- The geogrid must be able to absorb the applied loads radially, especially under service load conditions (low strains of 0% to 2%).
- Traffic loads applied to the aggregate layer are dynamic in direction and intensity, whereby the granular structure of the base course is potentially loosened and destabilised.
- Geogrids with high radial stiffness in the service load range (Topic 4) absorb the loads optimally and transfer them safely.

Figure 9 Secugrid® samples punched out at various angles to determine the radial stiffness



- For the absorption of loads, the absolute values of the radial stiffness are essential and not the ratio between highest and lowest value. In Figure 10, Secugrid® and Combigrid®, respectively, show high minimum values and high reserves in the main direction of tensile strength (0° - 180°; 90° - 270°).
- High radial stiffness leads to high resistance against deformation and increases the safety and serviceability of a construction.

Advantages of Secugrid®/Combigrid®

- ✓ Superior radial stiffness under typical service load conditions in comparison to other reinforcement products (Figure 10).
- ✓ Additional high reserve of strength (safety) in axial direction (longitudinal/transverse) compared to other multiaxial geogrids.
- ✓ Secugrid®/Combigrid® Q geogrid types provide the ideal and approved structure for reinforcement and stabilisation at the same time.
- ✓ Reduction of base course thickness due to a high radial efficiency.

TOPIC #6:
Construction Strain

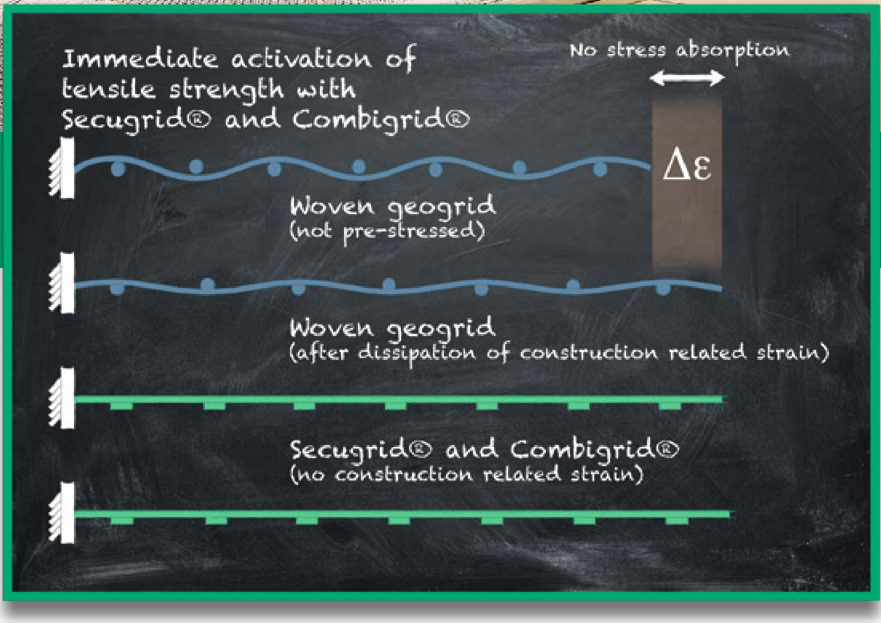


Figure 12 Secugrid®/ Combigrid® products without construction-related strain immediately transfer loads when covered with soil

0% of construction strain: safe and effective construction

Basic Information

- The construction-related strain is the initial strain of a product which is directly available after installation and before the tensile strength of the product can be activated (due to the possibility of an undulated product layer, see Figure 12, top).
- For a reinforcement product with construction-related strain, stress absorption is effective only when this strain is overcome.
- The standardised tensile test according to EN ISO 10319 defines a preload to be applied to the respective product in order to avoid possible construction-related strain influencing the stress-strain behaviour (e.g., wovens, woven geogrids, etc.).
- In the technical data sheet, the parameter for tensile strength is normally given in kN/m, after the construction-related strain has been eliminated (pre-stress).
- The construction-related strain depends on the manufacturing technology of the reinforcement product:
  - Flexible, woven products usually exhibit a construction-related strain.
  - Stiff products allow for immediate force absorption.

Figure 11 Installation of Secugrid® (no pre-stressing required)

Effects

- Reinforcement products showing - construction-related strain deform first without considerable force absorption. Only after reduction of this additional strain can the reinforcement product absorb tensile forces (Figure 12).
- A reinforcement product without construction-related strain mobilises tensile forces immediately and does not exhibit a delayed efficiency.
- Products that exhibit construction-related strain should be pre-stressed on site in accordance to the procedure used in the tensile test (EN ISO 10319).
- No construction-related strain means a higher effectiveness of the reinforcement product.

Advantages of Secugrid®/Combigrid®

- ✓ A highly efficient reinforcement due to a constructional strain of 0%.
- ✓ Immediate force absorption without construction-related strain in the reinforcement product.
- ✓ Fast and safe installation of the reinforcement and thus a very economical and safe design.
- ✓ Higher safety level and less deformation for the construction.

TOPIC #7:
Torsional Rigidity

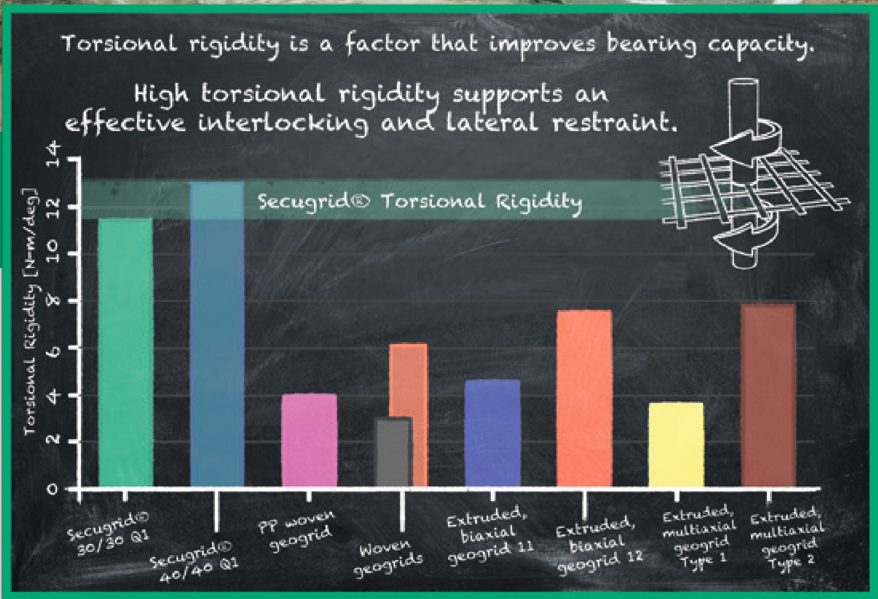


Figure 14
Torsional rigidity of different geogrid types

Stiff geogrid structure supports granular particles

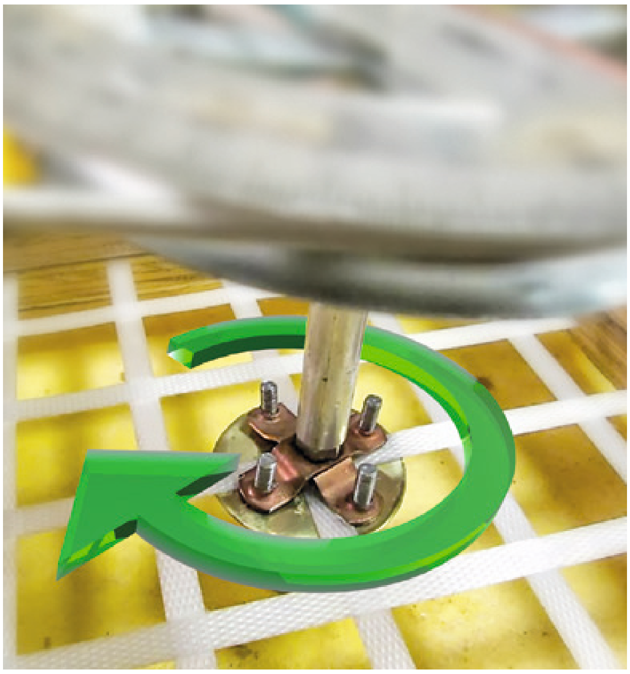
Basic Information

- Trafficking base courses causes shear strains, which differ with regard to their intensity and direction.
- The torsional rigidity defines the resistance of a geogrid against torsion.
- Tests carried out in the USA in the 1990s showed a relationship between the effectiveness of a geogrid and its torsional rigidity [Kinney & Xiaolin, 1995].

Effects

- By utilising a geogrid with a high torsional rigidity, the granular structure of the base course is optimally supported and radial shear stresses are absorbed.
- High torsional rigidity ensures that movements within the granular material are reduced, thus minimising deformations.
- A higher torsional rigidity ensures a better load distribution into the geogrid structure.

Figure 13
Application of torsional stress to Secugrid® geogrid sample



Advantages of Secugrid®/Combigrid®

- ✓ Optimum, rigid reinforcement of the construction resulting from high torsional rigidity in the Secugrid®/Combigrid® geogrid structure.
- ✓ High resistance of the load-bearing system as against stresses caused by traffic and dynamic loads.
- ✓ Very good support and lateral restraint of the base course material due to an optimum torsional rigidity of the Secugrid®/Combigrid® geogrid structure.
- ✓ High level of safety for the stability of the total system.

TOPIC #8:
Robustness

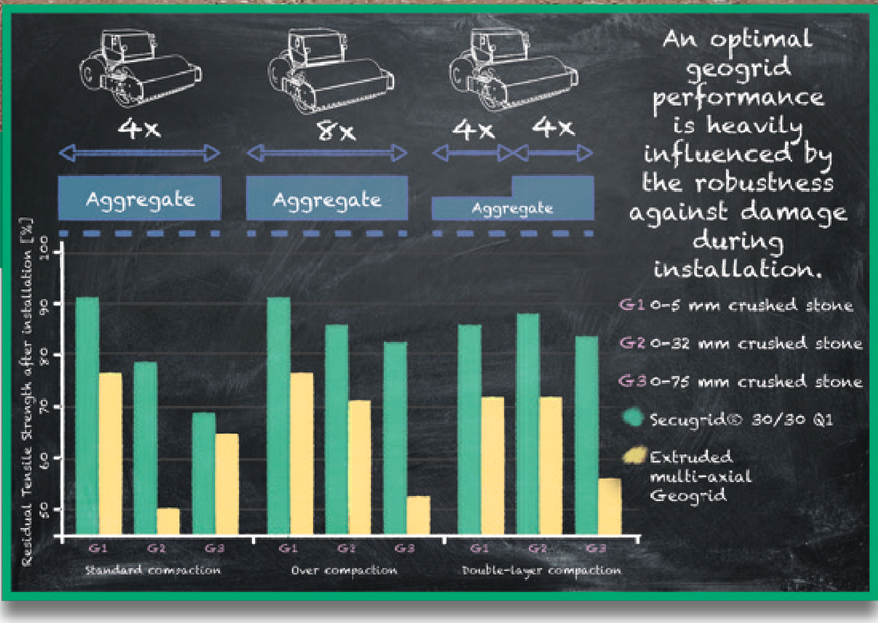


Figure 16 Maximum installation damage reduction factors (“RF_{ID} / A_2”) resulting from tensile testing carried out by BTTG/UK using samples which were taken from installation damage tests carried out by ERA/UK

Mechanical and environmental effects on the geogrid quality

Basic Information

- Project-specific parameters like type of fill, soil pH-value and dynamic loads influence the tensile strength of a geosynthetic and, thus, its effectiveness.
- The robustness is the resistance of the geogrid against loads, resulting from, for example, product transport, installation, compaction, UV exposure and chemical effects.
- The robustness of a geogrid product against all individual factors is determined by laboratory or in-situ testing.

Effects

- Greater residual tensile strength (extensional stiffness) as a result of greater robustness.
- Products manufactured of mono- and/or multifilament yarns are likely to be damaged by sharp-edged particles (e.g., crushed sand). Consequently, the available residual tensile strength of the reinforcement is in parts considerably reduced [Source: Newsletter No. 18, Institut für textile Bau- und Umwelttechnik, tBU, Greven].
- A sufficiently robust geogrid provides longer service life, higher effectiveness and a higher level of safety for the total construction.
- Based on general experience and proofs there are – depending on the manufacturing type and raw material – considerable differences in the robustness of geosynthetics (pre-stressed, laid, woven geogrids and wovens) (Bauen mit Geokunststoffen, Handbuch vom Schweizer Verband für Geokunststoffe, SVG – Building with Geosynthetics – a Handbook for Geosynthetic Users, as published by the Swiss Association for Geosynthetics SVG).

Figure 15 Installation damage factor (“RF_{ID} / A_2”) determined by a field trial in a quarry

Advantages of Secugrid®/Combigrid®

- ✓ The pre-stressed, monolithic bars of Secugrid® and Combigrid® exhibit exceptional robustness against installation damage even under extreme conditions.
- ✓ Comparative installation damage tests confirm the excellent robustness of Secugrid® and Combigrid® (Figure 16).
- ✓ Due to greater robustness and residual tensile strength, a longer service life and a higher safety level can be achieved in the reinforced construction.

TOPIC #9:
Bond Efficiency

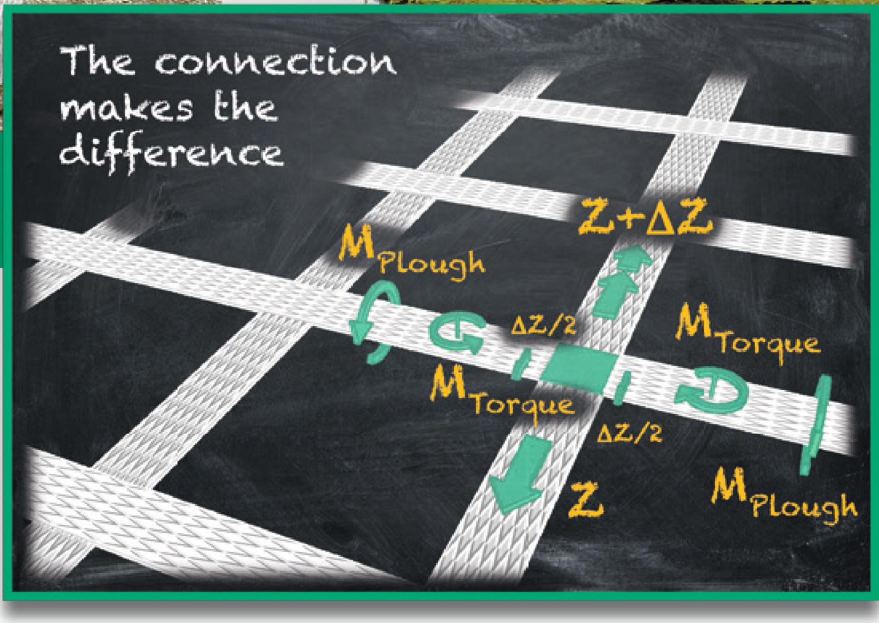


Figure 18 Mode of action of forces in the junction area

Good bond efficiency in the junctions optimises the load distribution in the geogrid structure

Basic Information

- Geogrids are usually differentiated by the following three production technologies:

  Extruded and pre-stressed (stiff junctions):
  For these products, a very high junction strength is required, as all forces, which are to be absorbed by the product, are distributed via the junction (longitudinal and transverse).

  Woven or knitted (weak junctions):
  For these products, the bond strength in the junction is mainly achieved by the polymeric coating. Accordingly, the connections are rather weak and can divert rather low tensile forces from longitudinal into transverse direction or vice versa.

  Laid and welded (strong junctions):
  The product group which includes Secugrid® and Combigrid® geogrids ensures an axial stress transfer into the monolithic bars through the junction area under typical site conditions. The welded junctions are stressed solely by shear forces.

- The effectiveness of geogrids has been tested in different research projects, wherein junction strength has always been a topic.
- Christopher (2007) found sufficient junction/connection strength to be almost exclusively required for service load conditions in the range of between 0% - 2% strain. In this particular range, where the geogrid is often subjected to maximum stresses, extruded and welded geogrids behave almost identically.
- This has been verified by the Montana II research project (Cuelho, Perkins 2014), as technical product parameters have been defined, which are linked to the performance seen in the trial. The junction strength is described as an important parameter at the stage of low deformations (rut formation). With larger deformations, junction strength becomes less important and other parameters (e.g., tensile strength, extensional stiffness, etc.) are then more indicative of performance.

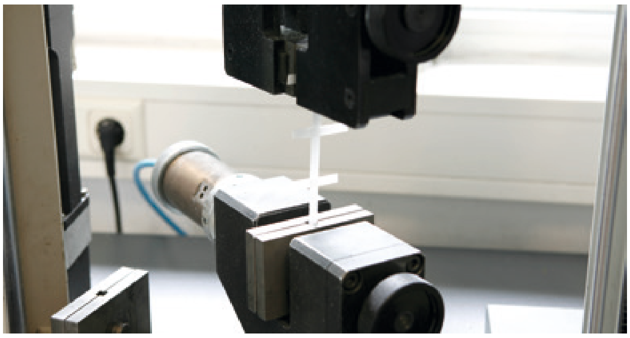


Figure 17 Junction Strength test using a Secugrid® geogrid sample

Effects

- Loads on top of base course layers, such as those produced by traffic, cause stresses within the granular material. The interlocking effect between granular particles and the geogrid apertures laterally restrains (stabilises) the base course aggregate.
- The torsional rigidity of the aperture, which is influenced by the junction efficiency, is of decisive importance to the interlocking and stabilisation effect.

Advantages of Secugrid®/Combigrid®

✓ In the relevant service load range at strains between 0% to 2%, the bond efficiency is extremely high. Even in the case of heavy loads (Montana I, 2009 and Montana II, 2014) clear advantages have been documented compared to products with stiff junctions (extruded).

✓ The good bonding efficiency generates the high torsional rigidity (Topic 7) of the geogrid and optimises the stabilisation/lateral restraint of the base course material.

TOPIC #10:

Bearing Capacity Design Methodology

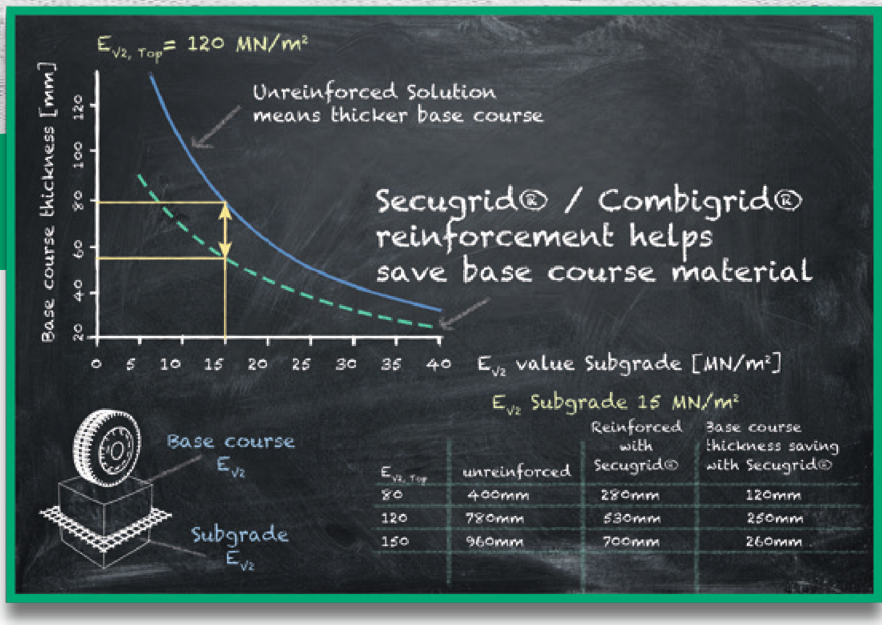


Figure 20 Comparison between non-reinforced and Secugrid® or Combigrid® reinforced, sub-base or base course

The E_{V2}-method

Basic Information

- The E_{V2}-method serves as a design method for unbound layers, in order to achieve a specified E_{V2}-value on top of the aggregate layer (e.g., base course or frost protection layer).
- The E_{V2}-value is determined by means of a plate loading test which is used for the determination of the bearing capacity and compaction quality of granular layers DIN 18134.
- The E_{V2}-method is used to design the product-specific layer thickness on the basis of the in-situ subgrade strength to achieve a defined bearing capacity on top of the granular layer ($E_{V2,\,top}$).
- Required bearing capacities following the procedure of DIN 18134 can be defined with, for example, 45, 80, 100, 120 or 150 MN/m².

Effects

- Transparent design method (optionally, plate bearing test is used for quality control).
- By using the E_{V2}-method, designed aggregate thicknesses without reinforcement can directly be compared to a design with geogrid reinforcement.
- More economical solutions are possible due to reduced aggregate layer thicknesses.
- More ecological and sustainable projects can be realised through the reduction of CO_2 emissions in the construction.

Figure 19 Plate bearing test according to DIN 18134 with a 300 mm diameter load plate

Advantages of Secugrid®/Combigrid®

✔ By using safe and simple Secugrid® and Combigrid® design tools, base course aggregate layers can quickly be designed with:

- SecuCalc design charts,
- SecuCalc design wheel, or
- SecuCalc design software

✔ After evaluation of numerous test trials and carried out projects, a considerable improvement of the cost effectiveness is possible in comparison to conventional methods and construction methods using other reinforcement products.

✔ Compared to conventional construction methods, Secugrid® and Combigrid® reinforced earth structures considerably improve the environmental performance as a result of essentially reduced CO_2 emissions.

TOPIC #11:
Serviceability Design Method

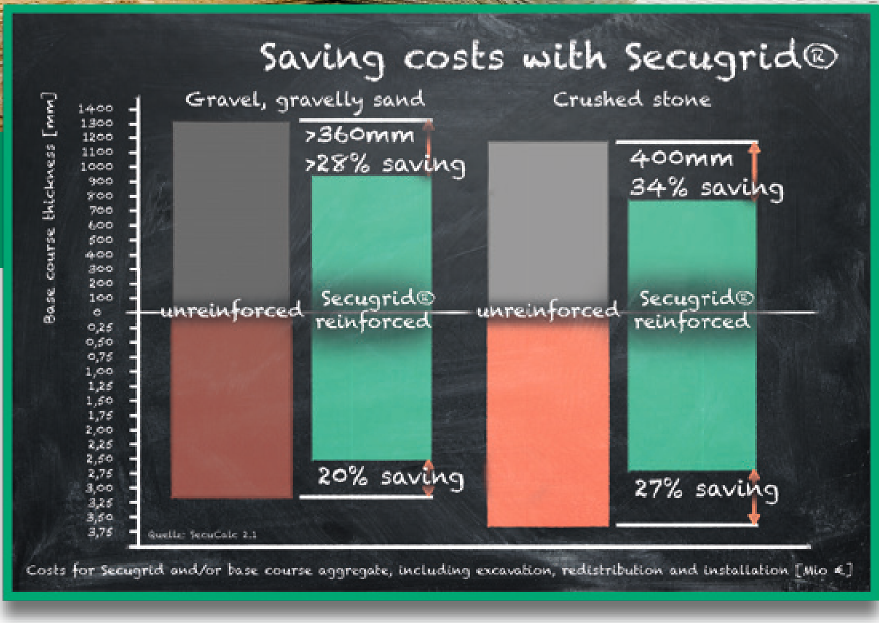


Figure 22 Exemplary (E_{V2top} = 120 MN/m²; E_{V2sub} = 7.5 MN/m²) comparison between unreinforced and Secugrid® crushed stone or gravel base courses including a cost comparison

Economic optimisation of temporary access road designs

Basic Information

- In order to achieve adequate serviceability for a base course, a maximum allowable rut depth must first be defined as a deformation criterion.
- In the next step, the base course is designed under consideration of the expected traffic load (number of axle passes) considering the operational life of the construction.
- At the end of the design life, the maximum rut depth must not be exceeded as a result of the applied traffic loading.
- Bearing capacity or undrained shear strength can be used to define the strength of the in-situ subgrade.
- A method which can be applied for all geogrid products is given in the “Recommendations for design and analysis of earth structures using geosynthetic reinforcements” (EBGEO) published by the German Geotechnical Society (DDGT), Germany.

Effects

- In order to consider the effective serviceability limit, this method offers increased cost effectiveness in comparison to the E_{V2}-method.
- The actual site conditions are used as a basis (subgrade, traffic passes, loads, etc.).
- Designs considering product-specific characteristics possibly provide greater economic results than designs carried out following the approach defined in EBGEO.

Figure 21 Low rut depth in the Secugrid® geogrid reinforced test section (in the front) compared to the unreinforced test section (in the back)

Advantages of Secugrid®/Combigrid®

- ✓ Significantly more economical designs can be carried out if the superior product specific properties of Secugrid® or Combigrid® are included.
- ✓ The saving potential of different reinforcement products can be verified by large-scale field trials.

References

BTTG Testing and Certification Ltd. (2008), "Tensile tests on installation damaged materials", BTTG Test Report No. 10/13308, UK, Nov. 2008

Christopher, B., "Junction-strength requirements for roadway design, construction", Geosynthetics, Industrial Fabrics Association International, Roseville, MN, Feb/Mar 2007.

DIN 18134 (2014), "Baugrund - Versuche und Versuchsgeräte – Plattendruckversuch", Beuth Verlag GmbH.

DIN EN ISO 10319 (2008), "Geokunststoffe - Zugversuch am breiten Streifen", Beuth Verlag GmbH.

EBGEO (2010), "Empfehlungen für den Entwurf und die Berechnung von Erdkörpern mit Bewehrungen aus Geokunststoffen - EBGEO", Deutsche Gesellschaft für Geotechnik e.V. (DGGT).

Kinney, T.C. and Xiaolin, Y. (1995), "Geogrid Aperture Rigidity by In-Plane Rotation". Proceedings of Geosynthetics '95. Industrial Fabrics Association International, St Paul.

Montana I: Cuelho, E. and Perkins, S. (2009) "Field Investigation of Geosynthetics Used for Subgrade Stabilization", Final report to the Montana Department of Transportation, FHWA/MT-09-003/8 193, 140 pp.

Montana II: Cuelho, E., Perkins, S.W., Morris, Z. (2014) "Relative Operational Performance of Geosynthetics Used for Subgrade Stabilization", Final Report, May 2014.

Institut für textile Bau- und Umwelttechnik, Greven, "Beschädigung von Geotextilien beim Einbau", Newsletter Nr. 18, September 2009.

RStO Richtlinien für die Standardisierung des Oberbaus von Verkehrsflächen, Ausgabe 2012, FGSV.

SVG Schweizerischer Verband der Geotextilfachleute, "Das Geotextil-Handbuch", 2003.

NAUE GmbH & Co.KG
Gewerbestrasse 2
32339 Espelkamp-Fiestel
Germany

Phone +49 5743 41-0
Fax +49 5743 41-240
E-Mail info@naue.com
Internet www.naue.com

Memberships of the NAUE Group

Approvals for the NAUE Group

Bentofix® BFG 5000
Bentofix® X2 BFG 5300

Secugrid® Q6 and R6