Base course stabilisation and reinforcement

Naue

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Building on sustainable ground.

Naue Secugrid® geogrids are produced in a unique manufacturing process. The structured monolithic reinforcing bars with a continuously oriented molecular structure are made of high-tensile, monolithically stretched polypropylene or polyester. Thus, they achieve extraordinarily high strengths at low strains. The longitudinal and transverse bars are firmly bonded in a proven welding process, resulting in a rigid, robust geogrid for soil reinforcement applications. Typical applications for Secugrid® geogrids are the stabilisation and reinforcement of base courses, reinforced slopes, retaining walls, slope stabilisation, basal reinforcement or 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.

Naue Combigrid® is the combination of a Secugrid® geogrid and a Secutex® nonwoven geotextile in one product that utilises state-of-the-art manufacturing techniques. Combigrid® provides stabilisation, reinforcement, filtration, separation and drainage in one product. This geogrid-nonwoven geocomposite is primarily used on soft soils with low bearing capacities, where stabilisation and reinforcement combined with separation and filtration is required, such as in unbound, dynamically loaded layers.

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Geogrid mode of operation

Geogrids reinforce granular layers

Basic information

- Analogous to reinforcement of concrete with steel, a geogrid absorbs the loads transferred to a granular layer (e.g. base course) via interlocking and friction (interaction with the fill material, see page 6).
- An open geogrid structure enables this exceptional load transfer.
- This increases the load distribution within a granular layer while transfer of stresses towards the subsoil is reduced.
- Geogrid stabilisation and reinforcement within 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 base course thickness combined with cost savings
- Reduction of rut formation
- Lateral restraint of the granular structure
- Stiffening of the granular layer (modulus of elasticity)
- Bridging of soft spots (inhomogeneous subsoils)
- Increase of serviceability and service life
- Considerable CO_2 reduction compared to conventional construction methods

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

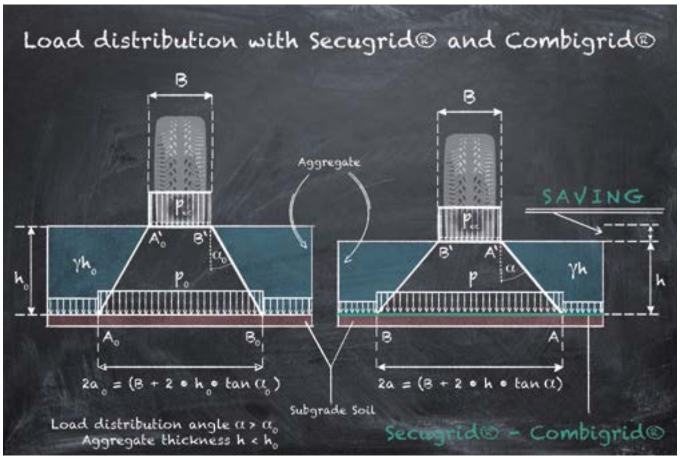


Figure 1: Saving of granular material in the base course by using Secugrid® and Combigrid® stabilisation and reinforcement products

Figure 2: Secugrid® geogrid reinforced stone columns carry a nearly 2-ton heavy delivery van during a live experiment (see the following QR-Code)

Interlocking and friction

Interaction of geogrid and soil

Basic information

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

Effects

- Interlocking and friction between the geogrid and the fill material transfer stresses towards the reinforcement and lead to the required load transfer/load distribution.
- The use of geogrids within a base course provides an interlocking between the aggregate and the geogrid aperture, preventing lateral movement of the fill.
- A high torsional rigidity (see page 16) of a geogrid minimises lateral movement.
- The embossed bars of Secugrid® provide a better frictional bond with soil compared to products with smooth surface, even at small displacements.
- An indicator of the interaction efficiency between a geogrid and the fill material is its frictional coefficient (combination of interlocking and friction).

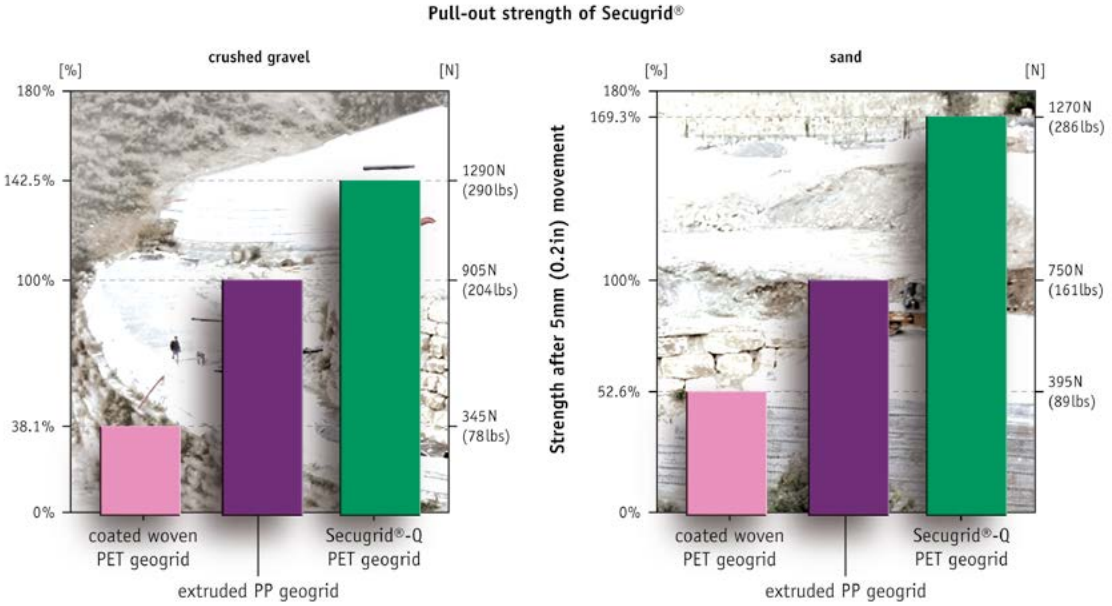


Figure 3: Comparison of pull-out behaviour of different geogrids installed in gravel and sand

Advantages of Secugrid®/Combigrid®

- ☑ The geometry and surface structure of Secugrid®/Combigrid® bars optimise the combination between interlocking and friction.
- ☑ The stiff bars (pages 10, 14, and 16) and the high surface roughness allow a strong bond with a wide range of fills and grain size distributions (see Figure 3).
- ☑ Due to the very high torsional stiffness (page 16), the stresses from the fill material can be efficiently transferred to the geogrid structure at small deformations, so that shear deformations in the fill material are reduced.
- ☑ Texturing is provided on both sides of the Secugrid®/Combigrid® bars to activate higher frictional resistance and improve the stress transfer between geogrid and soil.
- ☑ When using Secugrid®/Combigrid® geogrids, the earth pressure resistance absorbed by the bars is optimally transferred across the junctions via its bond strength (page 20).

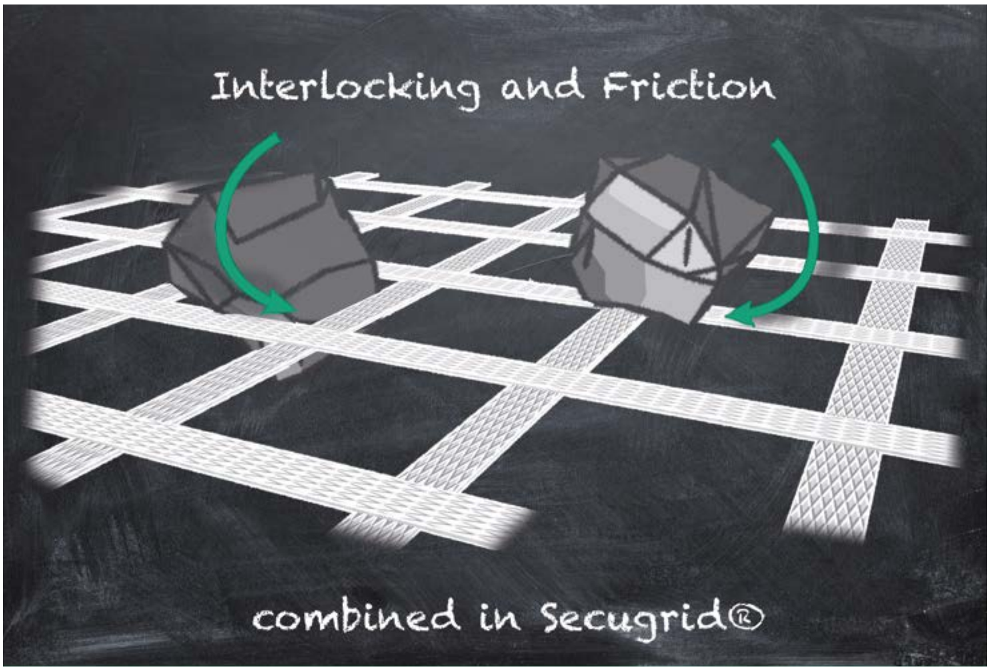


Figure 4: Schematic illustration showing interlocking (soil particle between bars) and friction (soil particle on top of the bar)

Tensile strength

Immediate stress absorption offers safe construction

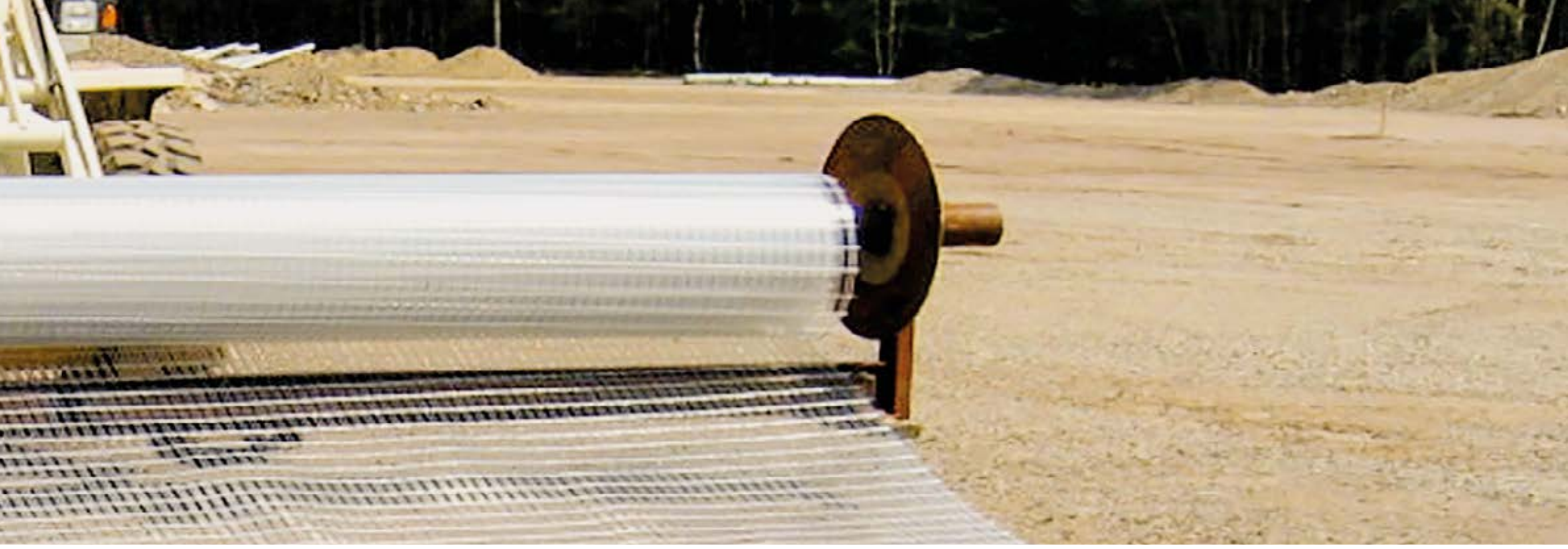
Basic information

- Granular layers cannot absorb tensile forces.
- Stresses which are absorbed by the geogrid via interlocking and friction, are distributed along the bars and across the junctions.
- Based on the applied load, the geogrid must absorb the maximum stress by providing sufficient tensile strength (expressed in kN/m).
- Analogous to the steel reinforcement within a foundation slab, the tensile strength of geogrid reinforcement has to be increased with decreasing bearing capacity of subgrade.
- For an optimum design, the resulting strain at the respective tensile strength must be checked for applicability (cf. extensional stiffness, see page 10).

Effects

- Applied stresses are absorbed and transferred via the geogrid reinforcement. Thus, excessive stresses in the fill material and subsoil (bearing failure) are avoided.
- Due to a higher tensile strength absorption in the lower strain range (0% to 2%), deformations in the base course are reduced more efficiently (cf. tensile stiffness, see page 10).
- When installed in base courses, the geogrid must be able to mobilise tensile forces in all directions (multiaxial) to distribute the applied loads efficiently (cf. radial stiffness, see page 12).

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



Advantages of Secugrid®/Combigrid®

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

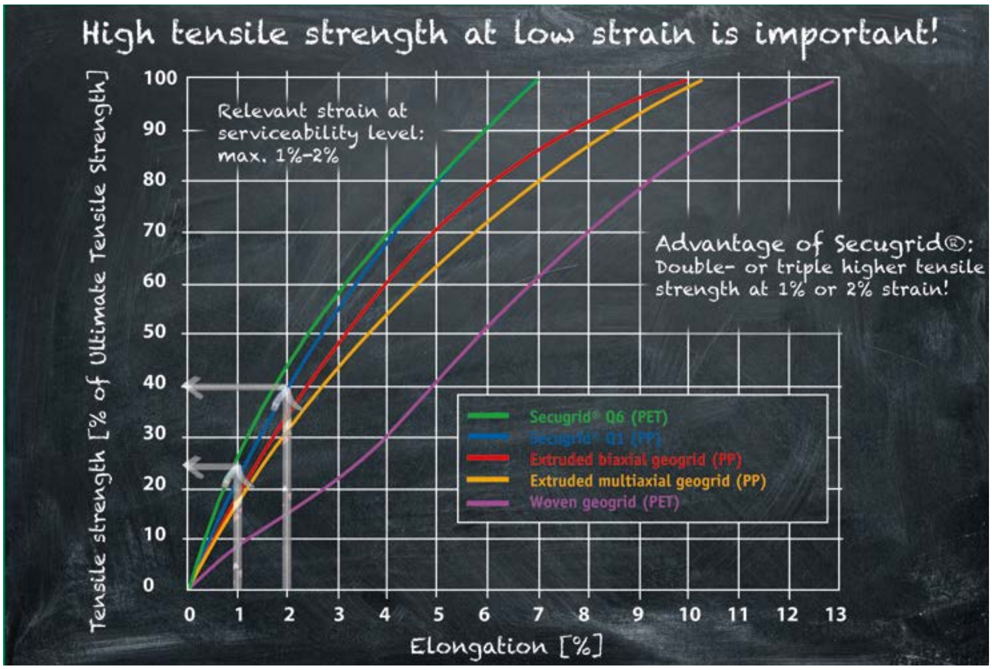


Figure 6: Exemplary stress-strain curves for Secugrid®, Combigrid® and other geogrids

Tensile stiffness

Effective reinforcement effect due to high strength absorption at low strain levels

Basic information

- The tensile stiffness or secant modulus (J) of a geosynthetic can be specified as a measure of its stress-strain-behaviour. The short-term tensile stiffness of a geogrid is determined based on the wide-width tensile test according to DIN 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 tensile stiffness for the range of ε_a to ε_b [kN/m],
F	tensile strength at a given strain value ε [kN/m],
ε	given strain [–].

- One indication of the effectiveness of a reinforcement product is a steep inclination of the stress-strain curve (high tensile strengths at low strains especially in the relevant serviceability state, mostly between 0% to 2%).
- Important: A high extensional stiffness must be given in all directions because the loads can be distributed radially within a base course (cf. radial effect of the reinforcement, see page 12).

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

Effects

- Exceeding the bearing capacity of a base course (e.g. heavy rut formation in an access road) destroys the stress-distributing interaction within the fill material (granular layers cannot absorb tensile forces).

- The service load range of a geogrid reinforcement within a granular base course layer is generally at a maximum strain level of 2% to achieve optimum combination 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).
- Products with lower extensional stiffness produce higher elongations compared to products with higher extensional stiffness at a comparable stress absorption level. This causes greater deformations and means that a higher ultimate tensile strength is required for the product with lower tensile stiffness if deformations are to be comparable.
- High extensional stiffness at low strain supports an immediate activation of the reinforcement effect at small deformations. This means that the loads are transferred more efficiently, and the risk of deformation is considerably reduced.
- An increase in serviceability by reducing the deformations is achieved with high extensional stiffness.

Advantages of Secugrid®/Combigrid®

☑ Higher extensional stiffness (especially in case of low strain levels) compared to, e.g. flexible geogrids or wovens made of comparable raw materials.

☑ High strength 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.

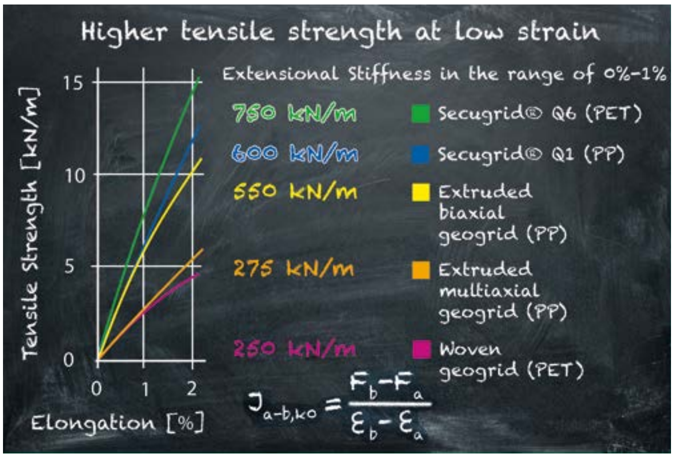


Figure 8: Exemplary stress-strain curves for Secugrid®, Combigrid® and other geogrids in the strain range of between 0% to 2% at comparable ultimate tensile strength levels

Radial effect

Load distribution in all directions (360° effect)

Basic information

- The load distribution within a base course can be 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 tensile stiffness (cf. tensile stiffness, see page 10) can be used as an indicator for radial effectiveness.

Effects

- The geogrid must be able to absorb the applied loads radially, especially under service load conditions (low strains of between 0% and 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 (see page 10) transfer the loads safely.
- For the absorption of loads, the absolute values of the radial stiffness are essential and not the ratio between the highest and lowest value. Secugrid® and Combigrid®, respectively, show - according to figure 10 - high minimum values and high reserves in the main tensile strength directions (0° - 180°; 90° - 270°).
- High radial stiffness leads to high resistance against deformation and increases the safety and serviceability of a structure.

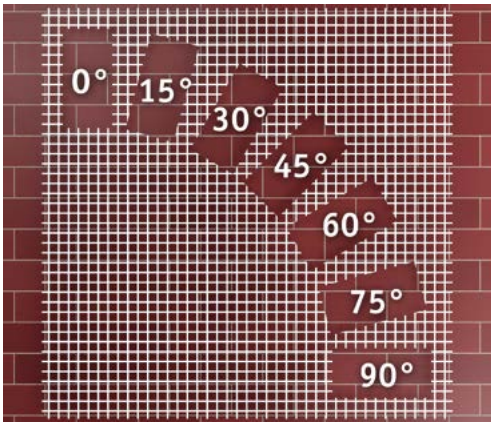


Figure 9: Secugrid® samples cut out at various angles to determine the radial stiffness

Advantages of Secugrid®/Combigrid®

☑ Superior radial stiffness under typical service load conditions compared to other reinforcement products (Figure 10).

☑ Additional high reserve of strength (safety) in the axial direction (longitudinal/ transverse) compared to other multiaxial geogrids.

☑ Secugrid®/Combigrid® Q geogrid types stabilise and reinforce.

☑ Reduction of base course thickness due to a high radial efficiency.

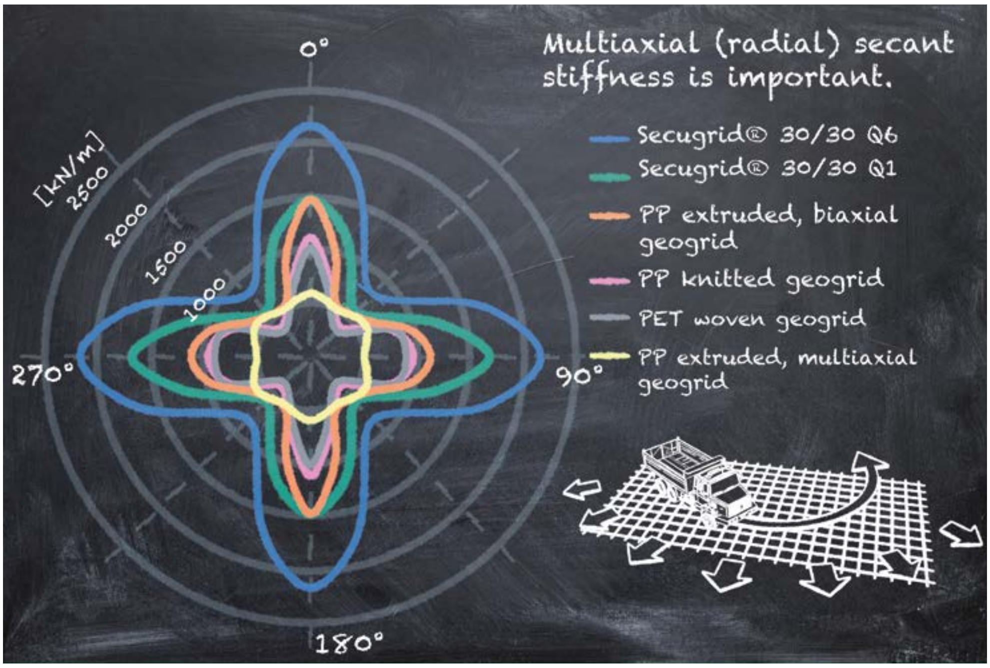


Figure 10: Radial secant stiffness of Secugrid®, Combigrid® and other geogrids at 0.5% strain and comparable ultimate tensile strength

Manufacture-related strain

0% of manufacture-related strain: safe and effective construction

Basic information

- The manufacture-related strain is the initial strain of a product which is directly available after installation and before the product's tensile strength can be activated (as a result of a manufacture-related undulation in the product, see Figure 12).
- For a reinforcement product with manufacture-related strain, the stress absorption is only effective if this strain is overcome.
- The standardised tensile test according to DIN EN ISO 10319 defines a preload to be applied to the respective product to avoid possible manufacture-related strain influencing the general stress-strain behaviour (e.g. wovens, woven geogrids, etc.).
- Usually, a data-sheet value shows the parameters of the tensile strength in kN/m after the manufacture-related strain has been eliminated (pre-stress).
- The manufacture-related strain depends on the manufacturing technology of the reinforcement product:
  - Flexible, woven products usually exhibit a manufacture-related strain due to undulation of the fibers.
  - Stiff products allow for immediate force absorption due to fully aligned tensile elements.

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

Effects

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

Advantages of Secugrid®/Combigrid®

☑ A highly efficient reinforcement due to a manufacture-related strain of 0%.

☑ Immediate force absorption without manufacture-related strain in the reinforcement product.

☑ Fast and safe installation and thus a very economical and safe execution.

☑ Higher safety level and less deformation for the structure.

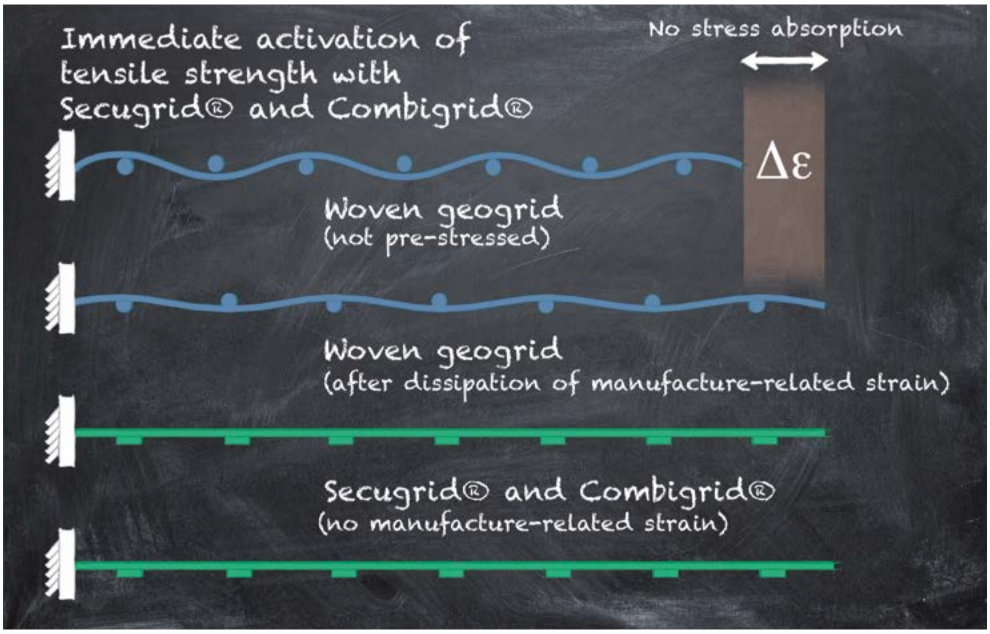


Figure 12: Secugrid®/Combigrid® products without manufacture-related strain immediately transfer loads when covered with soil

Torsional rigidity

A stiff geogrid structure supports granular particles

Basic information

- Trafficking base courses produces shear strains, which differ concerning 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

- Installing a geogrid with 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.

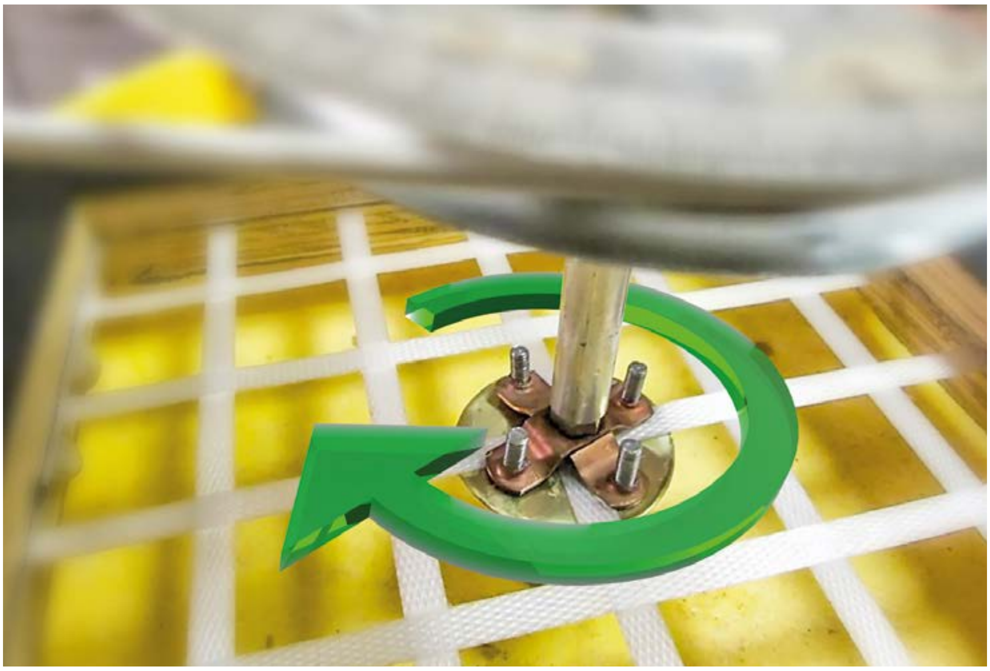


Figure 13: Application of torsional stress to Secugrid® geogrid sample in a test rig

Advantages of Secugrid®/Combigrid®

- ☑ Rigid reinforcement resulting from high torsional rigidity in the Secugrid®/Combigrid® geogrid structure.
- ☑ High resistance of the load-bearing system against stresses caused by traffic and dynamic loads.
- ☑ Very good support and lateral restraint of the base course aggregate due to high torsional rigidity of the Secugrid®/Combigrid® geogrid structure.
- ☑ High level of safety for the stability of the total system.

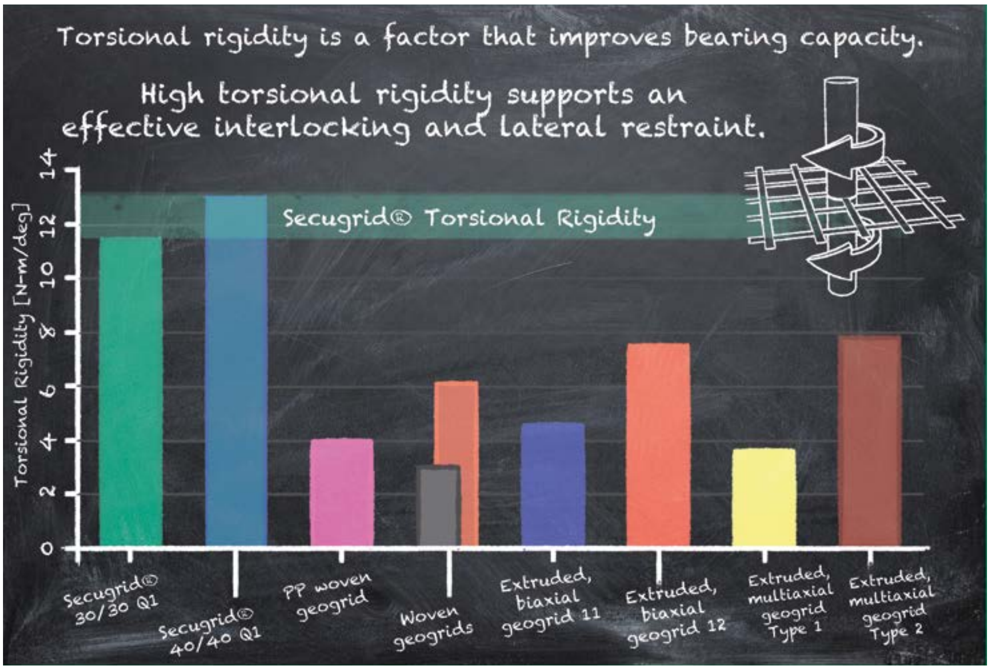


Figure 14: Torsional rigidity of different geogrid types

Robustness

Mechanical and environmental effects on the geogrid quality

Basic information

- Project-specific parameters, like e.g. the 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 stresses 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 reinforcement's available residual tensile strength is in parts considerably reduced [Source: Newsletter No. 18, Institut für textile Bau- und Umwelttechnik, tBU, Greven, 2009].
- A sufficiently robust geogrid provides a longer service life, a higher effectiveness and higher level of safety for the total construction.
- Based on general experience and proofs, there are considerable differences in the robustness of geosynthetics depending on the manufacturing type and raw material (pre-stressed, laid, woven geogrids and wovens) [see Bauen mit Geokunststoffen, Handbuch vom Schweizer Verband für Geokunststoffe, SVG / Building with Geosynthetics - a Handbook for Geosynthetic Users, published by the Swiss Association for Geosynthetics SVG, 2003].

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® (see Figure 16).

☑ Due to greater robustness and residual tensile strength, longer service life and a higher safety level can be achieved in the reinforced construction.

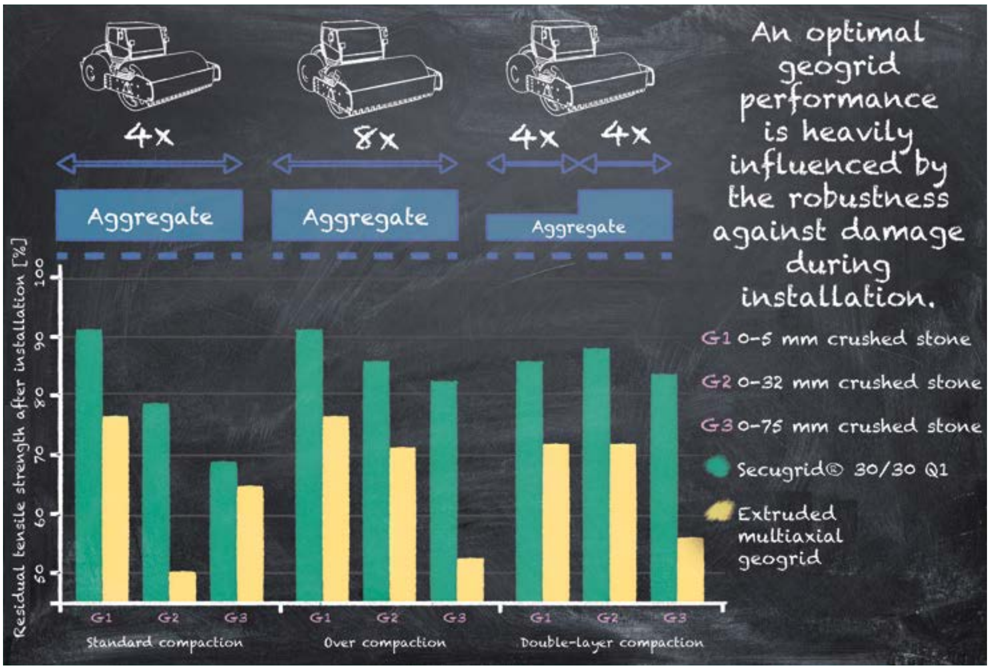


Figure 16: Maximum installation damage reduction factors ("RF_{ID} / A_2") resulting from tensile testing carried out by BTTG/UK using samples which were taken from installation damage tests carried out by ERA/UK

Bond efficiency

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

Basic information

- The following three production technologies usually differentiate geogrids:
  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 somewhat fragile and can divert relatively low tensile forces from the longitudinal into the 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 and safely distribute those at the connection.
- 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 between 0% - 2% strain. In this particular range, where the geogrid is often subject to maximum stresses, extruded and welded geogrids behave almost identically.
- This has been verified by the Montana (Phase 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 the 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, influenced by the junction efficiency, is decisive to the interlocking and stabilisation effect.

Advantages of Secugrid®/Combigrid®

☑ The bond efficiency is extremely high in the relevant service load range at strains between 0% to 2%. 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 (page 16) of the geogrid and optimises the stabilisation/lateral restraint of the base course material.

☑ Very good support of the base course material due to optimum torsional stiffness of the Secugrid®/Combigrid® geogrid structure.

☑ High safety for the stability of the entire system or construction.

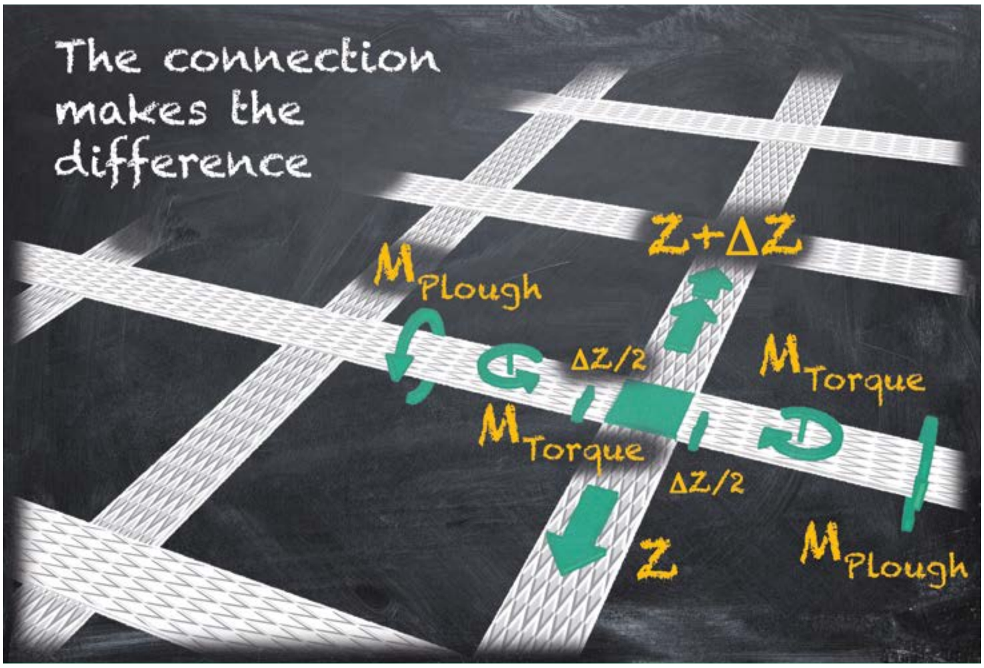


Figure 18: Mode of action of forces in the junction area

Bearing capacity design methodology

The E_{V2} method

Basic information

- The E_{V2} method serves as a design method for unbound layers 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 a plate loading test used to determine the bearing capacity and compaction quality of granular layers (DIN 18134).
- The E_{V2} method is used to design the product-specific layer thickness based on the in-situ subgrade strength to achieve a defined bearing capacity on top of the granular layer ($E_{V2,\ top}$).
- Required final bearing capacities can be defined with, for example, 45, 80, 100, 120 or 150 MN/m^2.

Effects

- Transparent design method (optionally, plate bearing test is used for quality control).
- By using the E_{V2} method, designed aggregate thicknesses without reinforcement (e.g. RStO-design) 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 by reducing CO_2 emissions in construction.

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

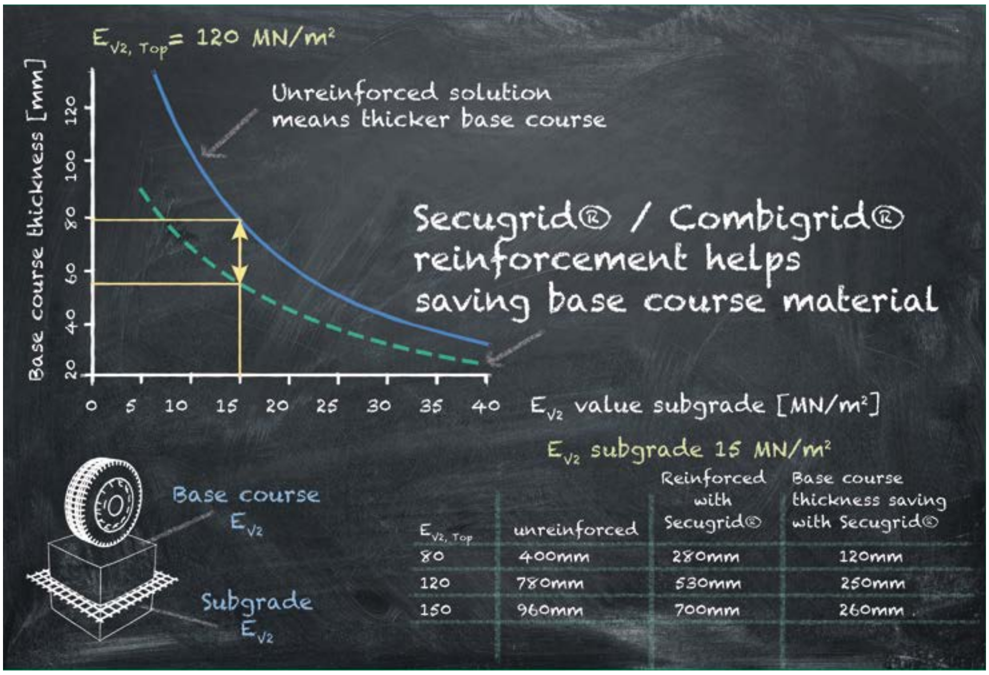
Advantages of Secugrid®/Combigrid®

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

- SecuCalc design charts,
- SecuCalc design software (Naue Portal)

☑ After evaluation of numerous trial sections and projects carried out, a considerable improvement of the cost-effectiveness is possible compared to conventional methods and construction methods using other reinforcement products.

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



E_{V2} subgrade 15 MN/m²

$E_{V2,\ Top}$	unreinforced	Reinforced with Secugrid®	Base course thickness saving with Secugrid®
80	400mm	280mm	120mm
120	780mm	530mm	250mm
150	960mm	700mm	260mm

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

Serviceability design method

The rutting performance method - 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 surface deformation/failure 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 road structure.
- At the end of the design life, the maximum rut depth must not be exceeded due to the applied traffic loading.
- Bearing capacity or undrained shear strength can be used to define the in-situ subgrade strength.
- 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 (DGGT), Germany.

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

Effects

- To consider the effective serviceability limit, this method offers increased cost-effectiveness compared 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.

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.

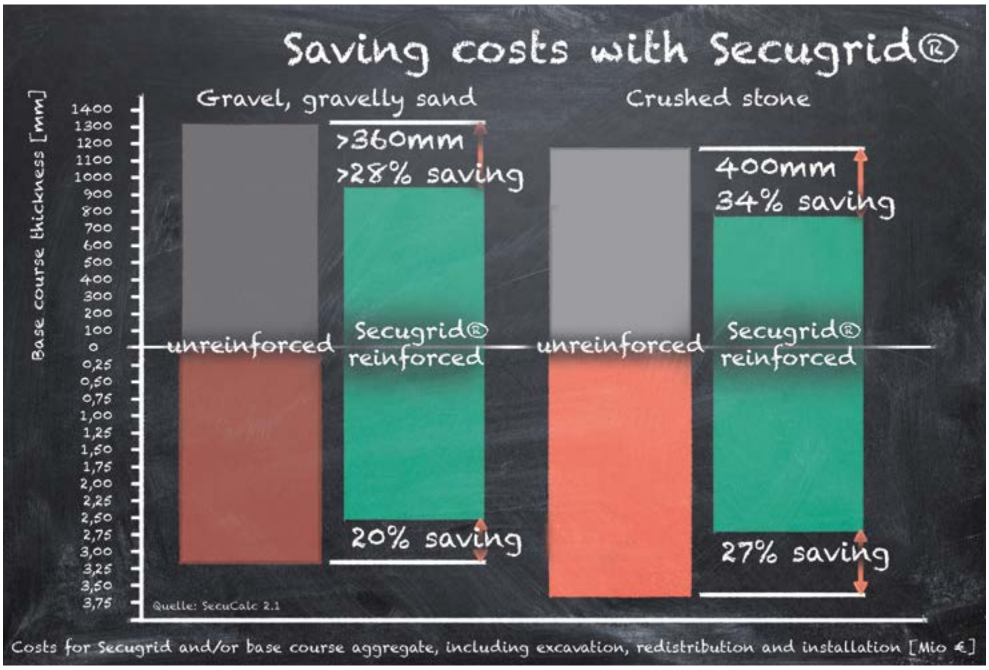


Figure 22: Exemplary ($E_{V2,\,top}$ = 120 MN/m^2; $E_{V2,\,sub}$ = 7.5 MN/m^2) comparison between unreinforced and Secugrid® reinforced crushed stone or gravel base courses, including a cost comparison

Learning from experience

Large-scale field test

To describe realistic load situations for geogrids used in base course stabilisation and reinforcement infrastructure applications, field trials with moving wheels are the preferred choice. Compared to simulations of wheel loads in the lab via cyclic plate load tests, the three-dimensional effect of particle rotation as well dynamic influences under the moving wheel can realistically be simulated in the field. In 2016 a large-scale field trial was performed in the municipality of Tostedt, Northern Germany.

In total, 8 test sections were constructed with the aim to determine the influence of geogrid stiffness, number of reinforcement layers and base course thickness on the performance of the test tracks overlying a soft clay (1.7% CBR target value). In all test sections a Combigrid® geocomposite was installed at the base, with the exception of the control section, where a geotextile separator was used. Sections 1.1 and 1.2 (Fig. 24) have used an additional intermediate Secugrid® geogrid. From left to right (section 1.1 to 1.8) the total geogrid tensile stiffness at 2% strain ($J_{2\%}$) decreases. Section 1.8 had the same stiffness as section 1.1 to 1.3 but was purposely underdesigned in thickness. The surface deformation in each section was assessed as relative rut depth (rut depth z_n vs. base thickness h_0) subject to the applied number of 10t axle passes.

Performance results

Figure 24 shows the rut increase (dimensionless factor for rut increase as a result of axle movements) vs. base course thickness for sections with the same tensile stiffness ($J_{2\%}$). Distributing the same stiffness of one geogrid onto two geogrids (section 1.3 vs 1.2) improves the performance, as the base course behaves more ductile. The performance of the thinnest section 1.8 shows the need for a minimum base thickness regardless of the tensile stiffness of the geogrid. This is essential to allow the reduction of the applied traffic load to an acceptable rate for the in-situ subgrade strength. Figure 25 shows the clear benefit of geogrid tensile stiffness $J_{2\%}$ to reduce rut deformation for all sections with equivalent base course thickness.

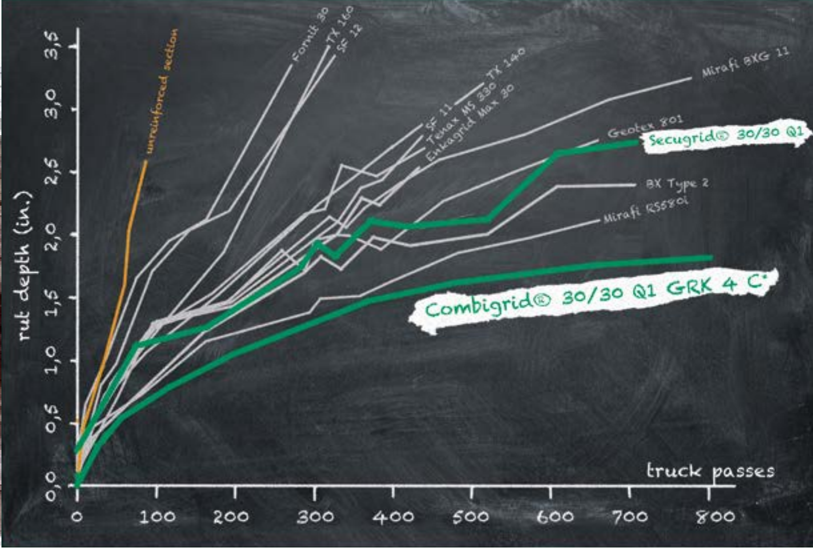


Figure 23: Comparison of Montana (Phase II, 2014) field trial results with Combigrid® performance from German field trial (2016).

Comparison of German results to field trial in Montana (USA)

In 2013 a comparable field trial to the one in Germany was performed in Montana, USA. 12 test sections with a 300mm thick base course were constructed over a weak subgrade (1.7% CBR). Different geosynthetic products were used, like e.g. biaxial woven, knitted, extruded & laid geogrids, extruded multiaxial geogrids, a woven geotextile and a nonwoven geotextile. The performance of each test section (rut depth vs. truck axle passes) was compared to a control section without any geosynthetic product in it but having the same thickness and subgrade strength. One of the tested geogrid products was a biaxial laid and welded geogrid Secugrid® 30/30 Q1 from Naue. None of the tested geogrids had a geotextile separator, so only the stabilisation and reinforcement benefit was examined. As the separation effect of a geotextile (like e.g. in the geocomposite Combigrid®) contributes substantially to the performance of the improved aggregate layer, results from the German field trial (2016) with Combigrid® 30/30 Q1 (section 1.5) were converted to the Montana research project, taking into consideration the difference in base course thickness and axle load and using the improvement factor of Combigrid® 30/30 Q1 as determined in the German research project. Adding the new performance curve to the curves of the other tested products from the US trial (Fig. 24) shows a clear advantage for Combigrid® 30/30 Q1 and its unique multifunctional benefit: stabilisation, reinforcement, separation and filtration in one product!

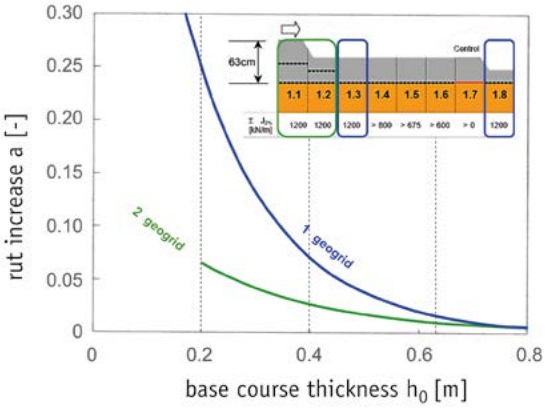


Figure 24: Rut increase vs. base course thickness h_0 for sections with same geogrid tensile stiffness $J_{2\%}$

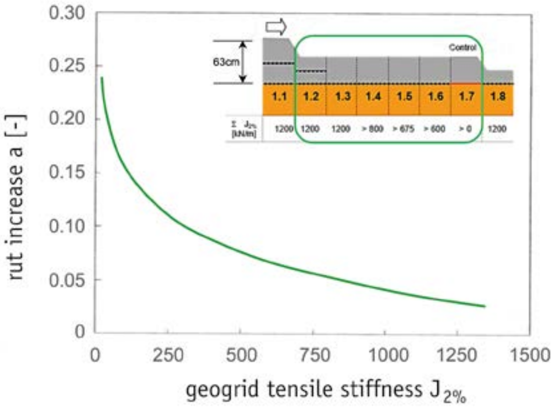


Figure 25: Rut increase vs. geogrid tensile stiffness $J_{2\%}$ for sections with same base course thickness

Increase of frictional resistance

Soil/geogrid interaction

Interaction between soil and geocomposites like Combigrid® is a very complex topic because it is affected by structural, geometrical, and mechanical characteristics of the geosynthetic and by the mechanical properties of the soil. For the geogrid component, three different interaction mechanisms can be identified:

- the friction between soil and the solid geosynthetic surface (Figure 27, Section A),
- the passive resistance mobilised against the bearing members/bars (Figure 27, Section B), a.k.a. lateral restraint or stabilisation,
- the friction between soil particles enclosed within the apertures of the geogrid and the surrounding soil particles (soil internal shear resistance).

To optimise interface friction between soil and the solid reinforcement surface (bars), the geogrid component of Combigrid® has an embossed surface. Especially with fine-grained subgrade soils like silts or clays, the increased surface roughness of the geogrid bars prevents slippage of Combigrid® on top of the in-situ subgrade. At the same time, the shear resistance between the smaller particles of the base course aggregate and the geogrid surface will be increased.

The picture at the top right corner of this page shows an imprint of the embossed bars of the geogrid component of Combigrid® on top of a cohesive fine-grained subgrade soil (boulder clay) after removal of the base aggregate together with the Combigrid® geocomposite. This demonstrates the good frictional interaction.

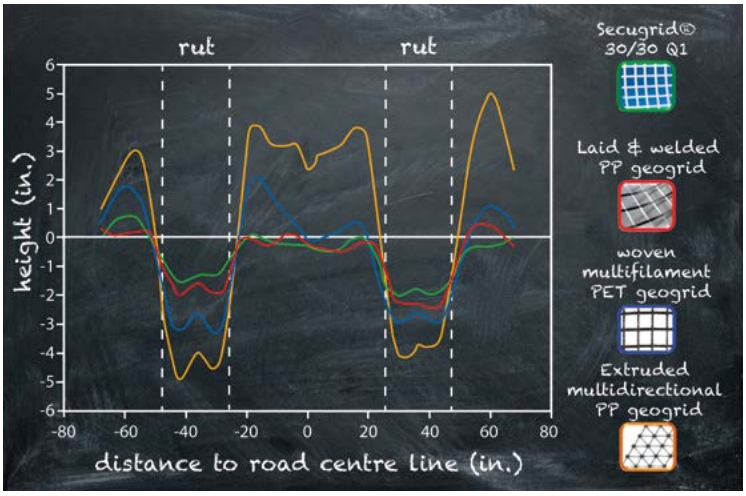


Figure 26: Comparison of the rut depth for 300 truck passes, field test in Montana, USA (Phase II, 2014)

Performance results

Figure 26 shows the rutting performance of 4 geogrid stabilised and reinforced base courses (thickness: approx. 300mm) installed over a soft clay subgrade (CBR: approx. 1.7%) from a large-scale field trial, carried out in 2014 in Montana, USA. The rutting performance is given at 300 truck passes (total weight of 3-axle dump truck: approx. 20.6t) for each of the illustrated geogrids. With reference to the representative stress-strain curves for the 4 tested geogrids (Figure 27), a direct correlation between the tensile stiffness and the performance of the geogrid stabilised and reinforced base course can be drawn. The geogrid with the highest tensile stiffness (Secugrid® 30/30 Q1) reduces rut deformations most efficiently, and the geogrid with the lowest tensile stiffness (extruded multidirectional PP geogrid) shows the weakest performance. The laid and welded PP geogrid is almost identical regarding its stiffness properties when compared to the laid and welded Secugrid® 30/30 Q1.

The main difference between both products is the surface structure. Where Secugrid® provides its typical diamond-shaped surface embossing, the laid and welded PP geogrid is completely smooth on the surface of its rigid bars. The higher surface roughness of Secugrid® 30/30 Q1 makes the difference in this case. Slippage of the finer grained fraction of the base course material is reduced as a result of an increased shear resistance. In addition to the lateral restraint effect, which is mostly generated by interlocking of the coarser aggregate particles with the stiff geogrid apertures, the frictional interaction between the geogrid surface and the surrounding fill obviously adds to the overall performance of Secugrid® and Combigrid® geogrids as well.

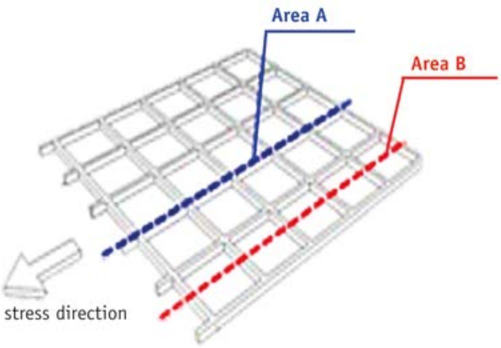


Figure 27: Interaction mechanisms of geogrids

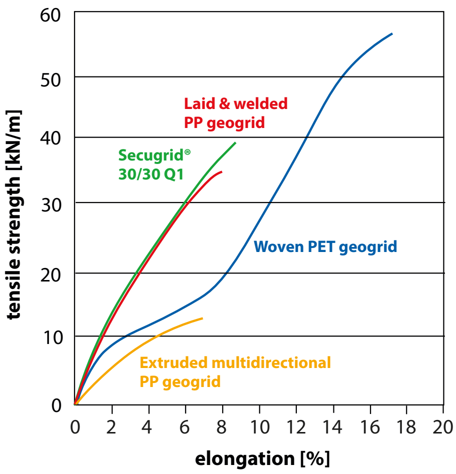


Figure 28: Stress-strain curves of 4 tested geogrids in Montana field trial (Phase II, 2014)

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Approvals for the Naue Group

CERTIFICATE 14/H218
Secugrid® Q6 and R6

CERTIFICATE 14/H218
Secugrid® HS R6

DIN EN ISO 9001
DIN EN ISO 50001
DIN EN ISO 14001

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