Combigrid®

SOIL REINFORCEMENT, SEPARATION AND FILTRATION
COMBINED IN ONE GEOSYNTHETIC

NAUE

»... combine knowledge, experience and technology and create a new dimension of a geosynthetic reinforcement ...«

Combigrid®

Reinforcement alone is not always enough. Geosynthetics are designed to perform specific functions and reinforcement is only one of them. For designs that also involve a need for filtration or the separation of fines, you may look to an extra dimension: Combigrid®.

Combigrid® geocomposites are the next generation of geosynthetic reinforcement products, a truly unique product that takes full advantage of state-of-the-art manufacturing technology. Combigrid® delivers reinforcement, filtration, separation and drainage in one composite material. These geogrids are used mainly in conjunction with soft and low CBR soils where soil reinforcement in combination with separation and filtration is needed, such as in base reinforcement, embankment reinforcement and load transfer platforms over pile caps.

Reinforcement is provided by Secugrid® geogrids, which provide excellent stress/strain characteristics and strength transfer in the geogrid bars, high strength and a high modulus at low elongations, durability and stiffness to promote radial interlocking, a reduced need for fill material, installation longevity, a decreased need for maintenance, and much more.

Filtration and separation functions are provided by Secutex®, a nonwoven, needlepunched geotextile that is placed between the Secugrid® bars during the manufacturing process.

Secutex® is bonded firmly between the reinforcement bars by NAUE's patented welding technology.

The three-dimensional nonwoven fibre matrix that Secutex® adds to Combigrid® acts as a separation layer between different grain size soils and ensures long-term separation and filter stability.

Such a separation layer is typically recommended in base course applications for subsoils with a CBR of less than 3% or in applications where fines should be prevented from moving into the reinforced aggregate above. The high elongation capacity of Secutex® nonwoven geotextiles ensures excellent resistance to damage. This robust characteristic of Secutex® allows them to easily accommodate irregular or soft subgrades.

With this excellent elongation property, the interlocking effect of Combigrid® with the fill material is not reduced - stress transfer to the geogrid through the high-strength Secugrid® bars is ensured.

LESSON #1:
Be an Early Riser

High-Strength at Low Strain = High Tensile Modulus
Combigrid®'s high-quality components define its success. As a reinforcement product first and foremost, the geogrid component (Secugrid®) exhibits high-strength at low strain, **especially in the key elongation range of less than 2%.** Depending on the manufacturing process geogrids typically have an elongation at failure of up to 15%, but in reality geogrid reinforced road pavements or reinforced earth structures are not designed for this high degree of deformation. The critical and realistic strain rate of geosynthetic reinforcement under serviceability conditions is typically less than 2%. Regardless of whether it is a geogrid only or a geogrid/nonwoven composite (Combigrid®), the interaction capability together with the stress/strain behavior of an installed geogrid should effectively reduce shear deformations in the soil as a result of a compressive loading regime. This is of great importance for frictional fills like e.g. sand and gravel as the strains to mobilize the peak shear strength under plane strain conditions are small (e.g.at 1.3% axial strain dense sand mobilizes its peak friction angle (Bishop 1966)).

Achieving proper strength here begins with the individual bars of a geogrid. You want those bars to mobilize high tensile forces at preferably low strain levels.

The one-dimensional bar characteristics of Combigrid® form a structurally sound and stable geogrid. The bars are uniformly extruded and drawn in the manufacturing process; this gives Combigrid® its unique high stress absorption capability at low strains. Then, the bars are welded together at the junctions - in Combigrid®'s case, with the nonwoven geotextile locked between the perpendicular bars - to create a rigid, high-performing structure. The manufacturing and joining of these bars provides superior stress/strain characteristics, especially in the key elongation range of less than 2%, for which many projects must be designed and by which geogrids are judged.

The tensile strength of Secugrid® (Combigrid®'s reinforcement component) is excellent at low elongation. Secugrid® bars have a very high modulus, which means they pick up stresses quickly. While Secugrid® typically has a maximum elongation at nominal strength of 8%, realistic design conditions ask for a strength transfer in the range of less than 2%. Secugrid® bars excel at these realistic design levels and show an optimum strength transfer in this design range, demonstrating a high modulus.

As the geogrid is much stiffer in tension than the base aggregate, lateral stresses and strains in the reinforced base aggregate are reduced and significantly less vertical deformation (for example, rut depth in an unpaved road) can be expected. Common applications in which this exceptional load management and long-term performance can be observed are in railway sub ballast reinforcement, roadway subgrade reinforcement, stabilization of wind farm access roads, crane working platforms and stockyards in harbors or container terminals. A geogrid's quality can be defined in many ways (long-term design strength, cost, etc.), but success begins with the individual bars. It is in these bars that project performance rests: strength transfer, elongation, installation and degradation resistance, sustainability, etc.. The tensile performance and dependability of Combigrid® reinforcement is rooted in its flat, extruded geogrid bars and how they mobilize high-strength at low strain.

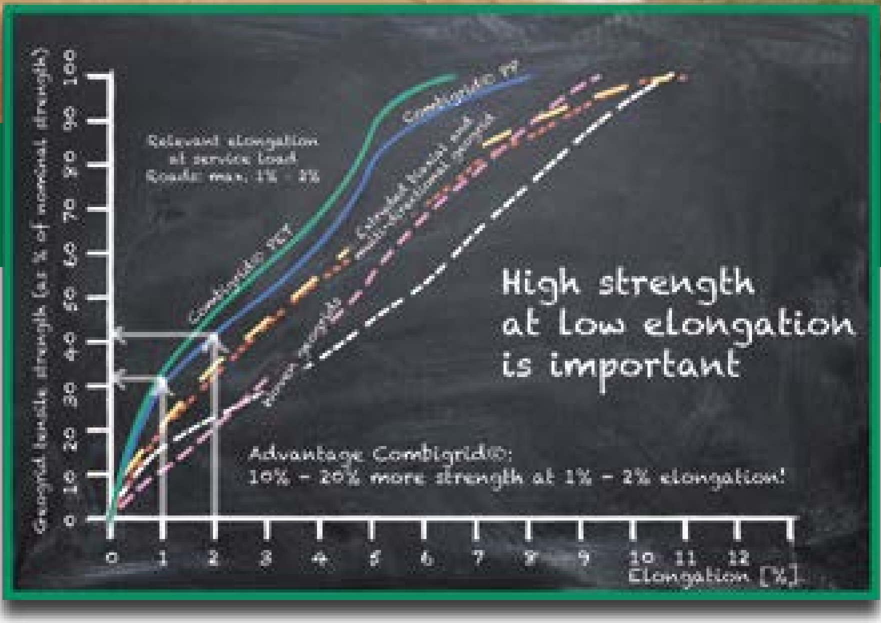


Fig. 2
Typical tensile strength/elongation curves for Combigrid®, Secugrid® and market available geogrids

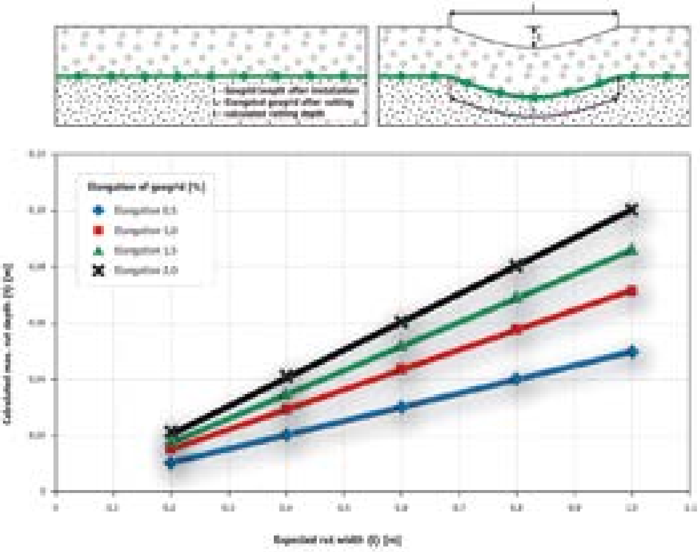


Fig. 1
Calculated rutting, resp. differential settlement based on elongation of a geogrid

LESSON #2:
Find Your Center of Strength

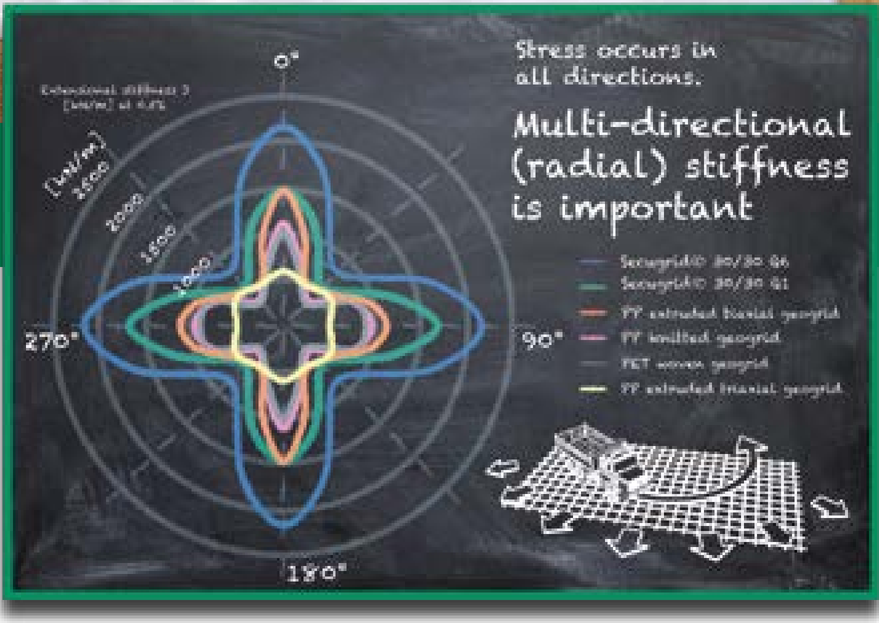


Fig. 4
Radial secant stiffness of Combigrid®, Secugrid® and other geogrids at 0.5% elongation

Radial Stiffness/Interlocking

The longevity (and economical performance) of a geogrid-reinforced road application is heavily dependent on the geogrid's ability to develop high shear resistance (also known as interlocking effect) between reinforcement and base aggregate. As a result of an optimum interlocking effect, lateral restraint of the base course aggregate is achieved, which as a result reduces vertical deformation (rutting).

Stresses from traffic loads, which are transferred to the base aggregate lead to an outward motion of the aggregate from the wheel, mainly in the direction of traffic flow and perpendicular to it. Due to shear interaction generated between the base aggregate and the reinforcement , the geogrid is mainly stressed in longitudinal and transverse directions (bi-axial). In applications where a defined direction of traffic flow does not exist, such as in large traffic areas like parking lots and container terminals the geogrid might also be stressed diagonally to the longitudinal and transverse direction. In this case "multidirectional" load transfer might be assumed.

For a geogrid to be well prepared for all applications and requirements (bi-axial and/or multi-axial) high radial stiffness at low strains is a desired performance parameter. This is the resistance with which the geogrid reduces lateral movement in the base aggregate in all possible stress directions.

Achieving success is a matter of finding true bi-axial strength and radial stress transfer. As noted in Lesson #1, the geogrid or geogrid/nonwoven composite should effectively reduce shear deformations in the soil as for frictional fills like e.g. sand and gravel the strains to mobilize the peak shear strength under plane strain conditions are small (e.g. < 1.3% for a dense sand).

Fig. 3
Combigrid® installed as base course reinforcement where multi-directional stiffness is of great importance

This is why the bars of the geogrid must possess a high modulus, reaching high strength at low strain. Now the strength of the geogrid junctions comes into play. The bars form the grid through which tensile forces are transferred, and the junctions hold the system together. Both longitudinal and transverse bars and junctions must be well-engineered for the reinforcement to perform its tasks properly.

The stiff, bi-axial geogrid bars of Combigrid® possess high multi-directional (radial) strength. The stability of the firmly welded flat junctions of Combigrid® creates a rigid, stable, two-dimensional geogrid that is just as strong in its transverse alignment as it is in its longitudinal alignment.

The absorption and distribution of tensile forces plus the aperture stability of Combigrid® locks the aggregate in place, even if radial movement occurs. (See Lesson 3 on Torsional Rigidity for greater detail.) Migration of aggregate and fines will be prevented as the aggregate interlocks laterally with the geogrid and stresses are transferred to the reinforcement. Combigrid®'s composite structure has an additional advantage: the embedded, highly durable nonwoven geotextile prevents smaller soil particles from migrating into the base course aggregate.

Reinforcement + Separation, Filtration and Drainage
= Total Radial Support.

As a single roll product, this composite reinforcement is economical to transport and easy to install. Most importantly, Combigrid®'s radial stiffness reduces long-term maintenance and extends installation services lives. It's 360° of protection.

LESSON #3:
Keep It Together

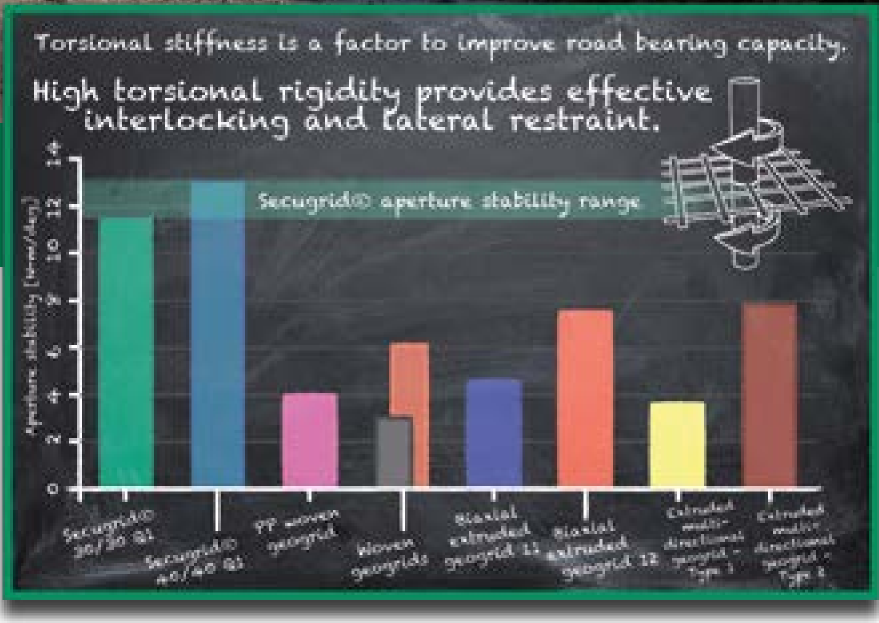


Fig. 6 *High torsional rigidity (also known as aperture stability) of market available geogrids*

The Importance of Torsional Rigidity

Combigrid® is used in many reinforcement applications, but roadway subgrade stabilization provides an excellent example for understanding the importance of torsional rigidity (aka Aperture Stability) in a geogrid:

When traffic passes over a geogrid-reinforced granular base course, a shear stress develops in the aggregate on the plane of the grid. This shear stress changes in magnitude and direction as the wheel passes. The changing direction causes a twisting motion in the geogrid. The main motion of the aggregate is outward from the wheel, but the stress on an individual particle during this migration changes from forward to outward, to backward.

Geogrids with high torsional rigidity provide greater resistance against torsional stresses, and this means that they provide more effective interlock with and lateral restraint of the base course material.

In roadway design, the torsional rigidity of a geogrid is an important factor in determining the traffic benefit ratio (TBR), which is the potential service life extension of a reinforced vs. an un-reinforced design. Here, we can consider the advantage of designing with a reinforcement technology and, furthermore, with which reinforcement. Combigrid® has performed exceptionally, well in independent tests (Christopher 2008) against other geogrids in assessing TBR impact. Combigrid® has outperformed other products in reducing permanent rut deformation, which is extremely important to TBR.

Fig. 5 *Interlocking effect of Secugrid®/Combigrid®. Radial movements on the base course causes a torsional momentum in the junctions*

Ruts make traffic less safe and lead to higher maintenance costs.

Not only does Combigrid®'s geogrid component (Secugrid®) interlock with the base aggregate and, thus, laterally confines the roadway subgrade, the geotextile component reduces the pumping effect (mixing of base aggregate with soft subgrade and vice versa) which could induce further rut propagation.

Torsional rigidity is not a new concept, but it hasn't enjoyed significant popular discussion in geotechnical engineering despite its importance. In the early 1990s, the US Army Corps of Engineers (USACE) conducted large-scale reinforcement tests at the renowned Waterways Experiment Station (WES) in Vicksburg, Mississippi. (You may find references to the "Geogrid Aperture Stability by In-Plane Rotation" testing in some literature.) While USACE focused on reinforcement solutions for paved light aircraft runways, the information gathered in the study, which was subsequently confirmed and expanded upon by Kinney and Xiaolin in the mid-1990s, has helped illuminate how and why subgrade behaves the way it does in multiple applications, how a geogrid responds, and why one geogrid reinforcement may significantly outperform another geogrid.

The manufacturing process of a geogrid is useful to know. Monolithic, extruded bars (e.g., Secugrid®) provide greater torsional rigidity than a flexible woven geogrid. Combigrid®'s flat, welded geogrid junctions perform exceptionally in "torsional rigidity" analyses.

The bottom line: higher torsional rigidity equals a better traffic benefit ratio. It means greater interlock strength. It means greater lateral restraint of base course. It means stronger reinforcement and more economical performance in far more reinforcement applications than just roadway stabilization.

LESSON #4:
Make a Good First Impression

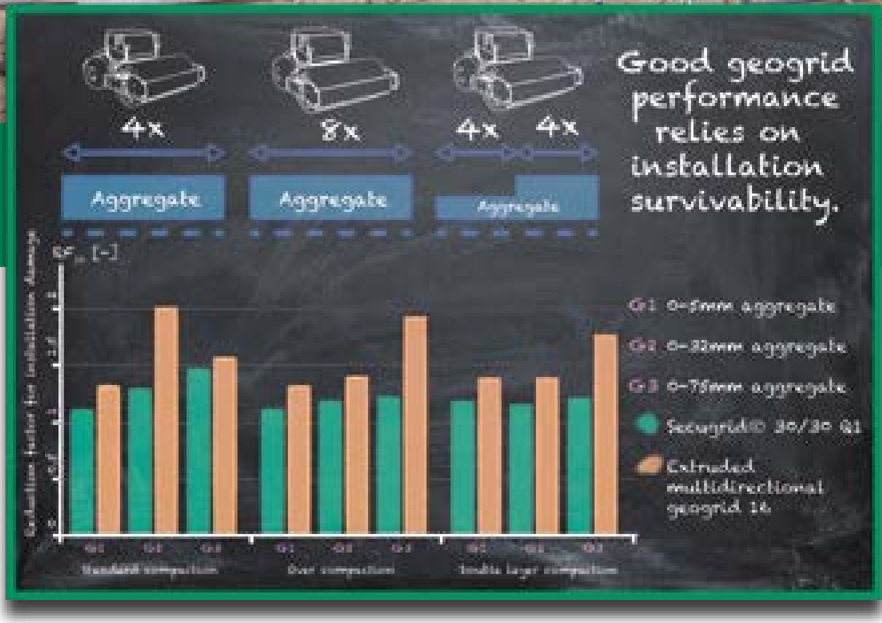


Fig. 8 *Maximum installation damage factors RFID from testing carried out by BTTG, UK on ERA installation damage samples*

Robustness

Modern construction practices may enable incredible installations and structures, but geotechnical construction sites are loaded with challenges to all of the construction materials to be used in the work. Weather exposure, heavy equipment, imperfect soils, inexperienced handling of materials, and many other risks are present. Any of them may lead to damaged materials before or during installation, and that damage can impact the performance of the material and not least the overall performance of the constructed geotechnical structure.

The robustness of a geosynthetic is crucial not only to its long-term performance but its ability to properly perform its engineered function at all. Geogrids, in particular, must be strong against the imperfect conditions that characterize nearly all construction sites.

Combigrid® is a robust reinforcement geogrid that is further enhanced by an embedded, extremely durable nonwoven geotextile. Bonded together in a single-layer product, these components provide the durability and strength to resist installation damage so that the reinforcement begins its service life in optimal condition - as every design intends.

Fig. 7 *Aggregate used over the geogrids during installation damage testing (from top to bottom): G1 (0 - 5mm) G2 (0 - 32mm) G3 (0 - 75mm)*

Fill material, for example, is rarely exact to a project's specifications. Soils and coarse stones always have variations, and the friction and stresses produced by these imperfections during the installation process can greatly affect a material's integrity. Its robustness is its resistance to these factors.

The embossed surface of the high-strength geogrid bars in Combigrid® additionally contributes to an increased material's frictional strength in service.

An added benefit to the robustness of Combigrid® is that for many designs it can save costs on the need for fill. The high strength of the geogrid composite increases the elastic modulus of a base course system to a point where the stiffness and load distribution capacity of the base course is improved. As such, less aggregate may be needed without reducing performance.

Reducing the amount of aggregate/fill on site can equate to significant transportation and installation savings: fewer heavy traffic shipments, quicker construction. The reduction in truck traffic, and the reduced need for aggregate extraction, also reduces the environmental impact of construction activities. This is of particular importance when sources of "good quality" aggregates are not available in the vicinity of the construction site.

Combigrid® is used in paved road systems, for unpaved wind farm access road, in container terminals, as reinforcement for working platforms and crane pads, as a cover system for tailings deposits, and in many other applications requiring strong reinforcement and benefitting from the addition of separation, filtration and drainage.

No matter where the installation takes place, the geogrid's survivability against the imperfections of fill and base course material allows good designs to become great projects.

LESSON #5:
A Place for Everything, and Everything in Its Place

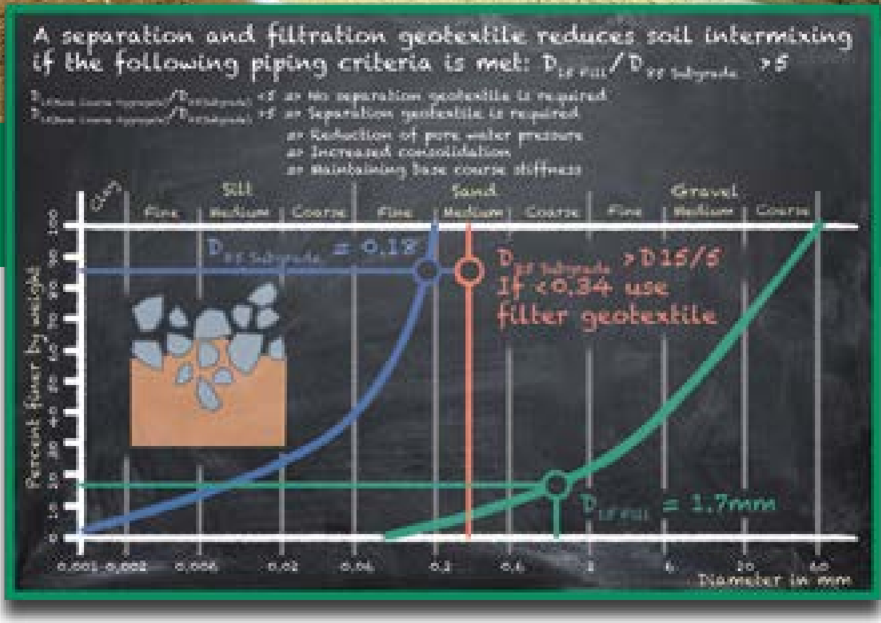


Fig. 10
Filter stability criteria, when a separation geotextile is additional needed in a soil reinforcement application

Long-Term Separation and Filtration

Reinforcement alone is not always enough e.g. in road applications. Soils that are soft or have a low CBR (e.g. < 3%) may require filtration or the separation of fines between the subgrade and the road base to ensure proper performance. In this case the geotextile fulfills the following functions:

- Separation: Prevention of subgrade soil intruding into aggregate base, and prevention of aggregate base migrating into the subgrade (Reduction of pore pressure in the subgrade)
- Filtration: Restricting the movement of soil particles, while allowing water to move from the filtered soil to the coarser soil adjacent to it
- Lateral Drainage: Lateral movement of water within the plane of the geosynthetic

Lack of separation leads to:
- Reduction of strength, stiffness and drainage characteristics of the base aggregate
- Greater risk of frost heave, due to susceptibility of fine grained subgrade

In their book "Principles of Pavement Design" the authors Yoder and Wiczak (1975) have highlighted the importance of a geotextile separator in road applications. They state that ... "as little as 20% by weight of the subgrade mixed in with the base aggregate will reduce the bearing capacity of the aggregate to that of the subgrade". This statement once again illustrates the importance of a geotextile separator with regard to the long-term performance of roads.

Multi-layer geosynthetic designs (individually installed geogrid reinforcement and geotextile separator) have long been used, but greater installation efficiency and project economy is possible. Combigrid®'s composite geotextile-geogrid construction enables a multi-functional single-layer design that performs the exact same functions previously achieved only with more complex, expensive designs. Combigrid® is not the only composite available. Some other companies offer geogrid-geotextile composites too, so it's important to distinguish between the different product compositions in order to identify the right material for an application. If the composite involves a nonwoven geotextile laminated to the geogrid, the bonding method is not dependable for a reinforced system design. The reinforcing element of such a product - the geogrid - may perform as designed, but the geotextile may delaminate due to rough handling during installation, soil or site weather conditions, coarse aggregate rubbing against the material, repetitive loads on the subgrade, etc.

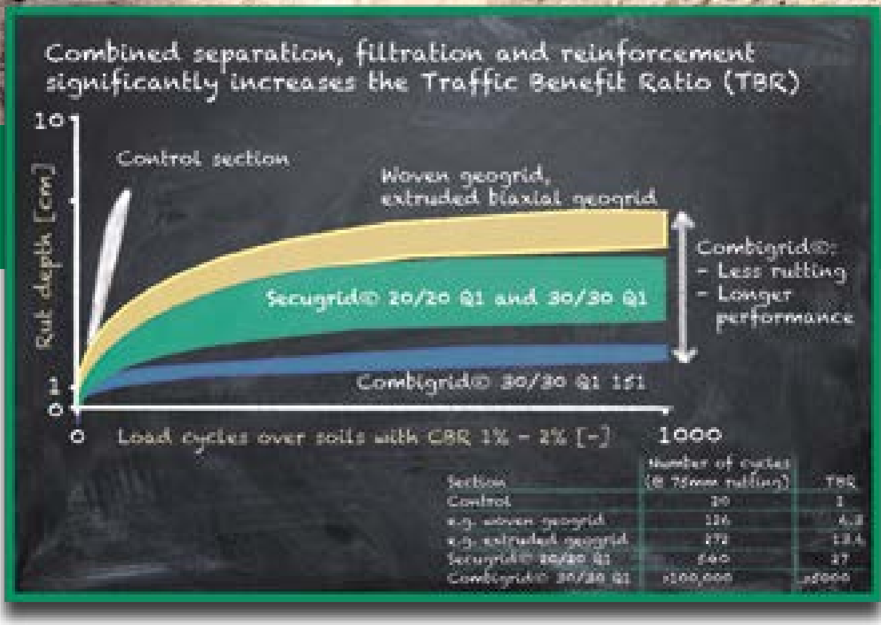
Fig. 9
Combigrid® used over a soft subgrade to achieve soil reinforcement and soil separation and filtration to ensure long-term performance

Conversely, the needlepunched nonwoven geotextile of Combigrid® is embedded within the geogrid during the manufacturing process. It is fused between the high-strength bars at the welded junctions. This is what makes Combigrid® a truly unique, "single-layer" composite product. In one engineered layer of the subgrade, the geogrid of Combigrid® provides high tensile strength to stiffen the subgrade and resists reflective cracking and rutting; while the embedded geotextile provides separation, filtration and drainage functions to enhance the product's protection against migrating/mixing fines. Without the risk of delamination, Combigrid® ensures not just reinforcement but long-term separation and filter stability.

Also of note, the highly durable needlepunched nonwoven geotextile provides additional strength to the roads during the presence of pore water pressure, such as a reinforced unpaved road may experience following heavy precipitation. Excessive pore water pressure can weaken a subgrade's soils to the point that a reinforced roadway system, despite a geogrid-stiffened aggregate layer, will exhibit a reduced elastic modulus from its as-constructed condition. Combigrid®, however, reduces rapid pore pressure build-up due to the durability and functionality of the geotextile component.

See Lesson #6 (Improved Roadway Performance) for further details on how this strength is verified by AASHTO's influential mechanistic-empirical (ME) design methodology.

LESSON #6:
Enjoy the Ride



Improved Roadway Performance

Geogrid reinforcement provides more economical and environmental base courses than non-reinforced aggregate layers. Road service lives are extended and less maintenance is required.

Combigrid®, with its high torsional rigidity and a strong interlocking of aggregate, provides exceptional resistance to rutting and prevents the migration and mixing of fines in the roadway system. This preserves the integrity of the road.

The Western Transportation Institute (WTI) and Montana State University carried out noteworthy field testing of the geogrid reinforcement and non-reinforced road systems, the results of which were published in a 2009 report with the Federal Highway Administration (FHWA). The performance of several geosynthetics commonly used for subgrade stabilization was included in the study. In the testing, a sandy clay soil was prepared as a weak roadbed material to a CBR strength of approximately 1.7% and a 20cm thick aggregate layer was compacted over the geosynthetic(s).

Fig. 11 *Base course aggregate installed over Combigrid® for improved roadway performance*

Trafficking was provided by a fully-loaded tandem-axle dump truck. Longitudinal rut depth, along with discrete measurements of displacement and pore pressure were monitored throughout the trafficking period. Rib damage/integrity was also evaluated for geogrid products used in the study.

Fig. 12 *Deformation response of a geogrid reinforced base course layer versus load cycles during full scale testing in a roadway stabilization study*

The results indicated that reinforcement technologies well-outperformed unreinforced designs, and that welded geogrids like Secugrid® and Combigrid® provided the best overall performance. Sections reinforced with Secugrid® and Combigrid® allowed the largest number of traffic movements to achieve a maximum rut depth between 75-100mm (3 to 4 inch). An important aspect of the WTI study is that it has provided strong field research supporting those using the AASHTO mechanistic-empirical (M-E) pavement design guide approach to new and rehabilitated road work. AASHTO's 2004 M-E design guide marked a significant step beyond the 1993 AASHTO guide in understanding roadway performance with established materials, taking into account key factors such as how the development of pore pressure reduces the effective stress in the subgrade and thereby reduces the subgrade stiffness and strength.

The AASHTO M-E design approach uses a finite element model to calculate pavement response and empirical damage models to relate strain-response to long-term rutting. Perkins, Christopher, Cuelho, Giroud, and Han have all contributed significantly to the field's understanding here, especially in regards to unpaved road performance and the response and beneficial impact of geogrid reinforcement.

Combigrid® provides geogrid reinforcement and geotextile separation, filtration and drainage functions to secure base course and support a road even against excess pore water pressure. Both lab and field data support the results. Most importantly, installation performance from highways to haul roads supports the use of Combigrid® for stronger, more economical, longer-lasting roads.

LESSON #7:
Lighten Up

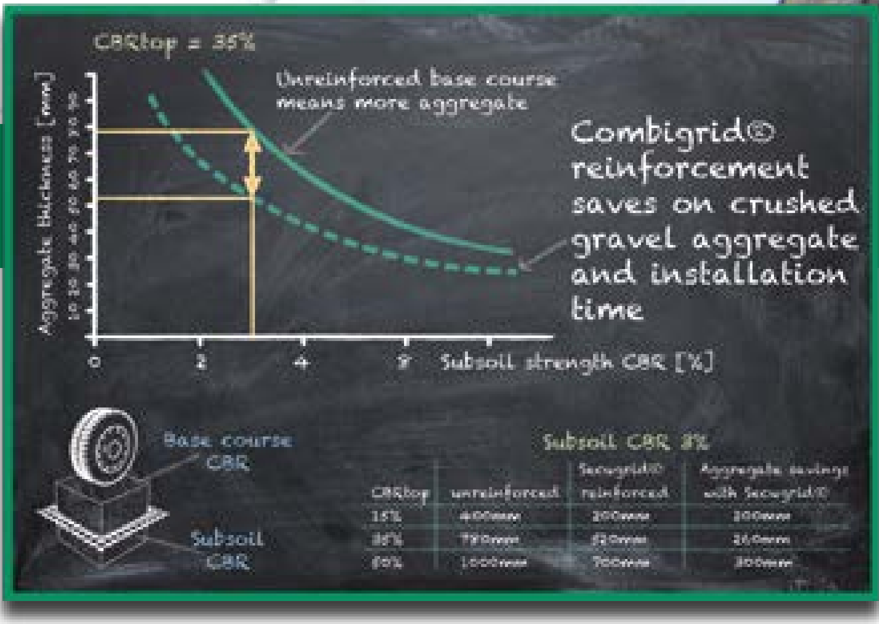


Fig. 14
Calculation diagram for crushed gravel as base course aggregate in unreinforced

Reducing the Need for Aggregate

As the costs of construction increase (e.g., materials, labor, fuel, aggregate taxes), the strength of geogrid reinforcement can make it possible to reduce the thickness of base course layers. And as the miles of roadway responsibility grow for cities, counties, and states, a significant scale of savings can be achieved simply by reducing some of the aggregate traditionally used in road construction.

Aggregate is an expensive commodity, not only in cost but in its environmental impact. Roads require specific types of aggregate to achieve the proper soil bearing capacity (even with the addition of geosynthetic reinforcement) for the expected traffic loads. That aggregate is rarely available near to the site, so it must be quarried, processed and transported from somewhere.

Quarrying and processing aggregate to meet common project specifications is an intensive process, and heavy haulage of suitable aggregate to site is costly and polluting. Traditional construction practices such as these are major reasons why construction has a terrible carbon footprint and real economic cost.

Combigrid® reinforcement decreases the dependency on base course thickness because of the superior stress/strain characteristics of its geogrid bars. The elastic modulus of the base course is improved; loads are better distributed; aggregate does not migrate laterally or mix vertically. The road provides greater resistance to vertical stresses (e.g., reduced rutting or reflective cracking).

In short, the installation of Combigrid® saves on aggregate today and maintenance tomorrow.

An added benefit of a decreased need for aggregate is that roads that lead to the construction site are better preserved. Smaller communities with lower road budgets are often the places through which heavy trucks pass on their way to a construction site. These vehicles include aggregate haulers. Reducing the volume of aggregate that must be transported helps better preserve all the miles of road not necessarily designed (or reinforced) to support sustained high loads.

Each day we learn more about how greener engineering practices are also economically smarter. Geosynthetics have continuously shown a positive impact. For road construction, Combigrid® geogrid reinforcement strengthens the prepared subgrade so significantly that the overall aggregate thickness can be reduced, which yields savings and healthier performances well beyond the immediate project's cost sheet.

Fig. 13
Unrolling and overlapping of Combigrid® over a soft subgrade

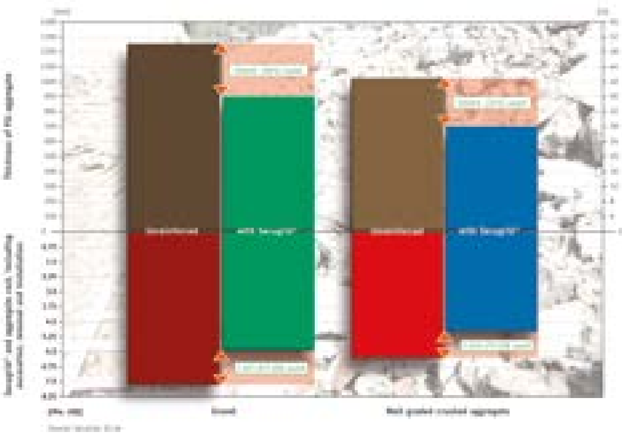


Fig. 15
Aggregate thickness and cost savings for unreinforced and Combigrid® reinforced unpaved roads

LESSON #8:
Watch the Bottom Line

Fig. 16 *Cost savings with installation of Combigrid® (including saving of aggregate due to no intermixing into the subgrade)*

Saving Cost on Installation

Poor-quality soils and sites with low CBR (e.g., < 3%) may require more than reinforcement. In the past, a separation and filtration geotextile was installed in order to shore up the soil. This was part of a more complex, multi-layer geosynthetic reinforcement system. The construction of these single layers took additional time for ensuring quality of aggregate installation and consistency and stability of the overall system. While this approach is still used, it's entirely possible to serve the reinforcement, filtration, and separation needs with a single layer within the subgrade system. Combigrid®, the single-layer composite reinforcement product, provides that answer.

How does this functional performance save on installation costs?

With its durable, needlepunched, nonwoven geotextile secured between the high modulus bars of the geogrid, Combigrid® provides exceptional separation and filtration stability. (See Lesson #5 for more about separation and filtration.) This construction prevents the fines from the subgrade from migrating vertically between road base layers. Simultaneously, the high-strength matrix of the Secugrid® geogrid reinforcement component laterally restrains the aggregate.

The thickness of the aggregate layer can be reduced, when Combigrid® reinforcement is installed.

Commercial aggregate is an expensive material for any geotechnical project. Costs include the basic rock cost, loading the rock, hauling it, spreading the material, and compaction of the aggregate. The distance to the location of the pits from which the rock has been acquired factors strongly into the cost, though local sources can be expensive too, considering the volume of aggregate needed for infrastructural projects.

Labor costs involve active installation time and passive time, as geotechnical site preparation must be undertaken carefully, and many steps must be taken care of before additional work, such as the placement of the next truckload of aggregate, can be performed.

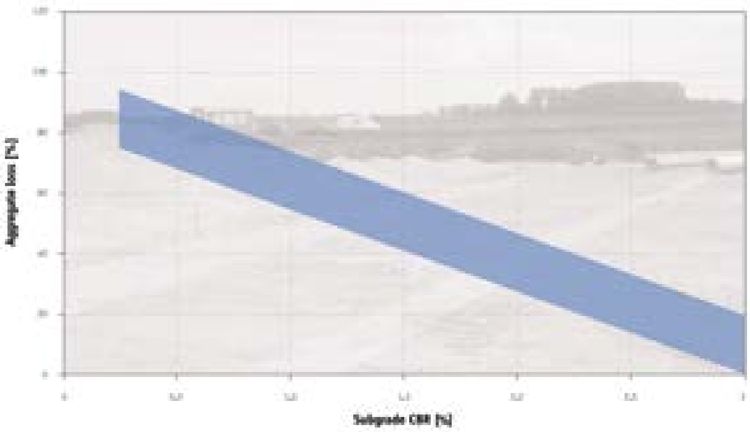
With so many cost variables to consider, any reduction in the need for aggregate can yield substantial savings on raw materials, transport, site labor, and the overall cost of the open construction window. Combigrid®'s high tensile strength at low elongation stiffens the reinforced base course layer.

The result is a stronger subgrade with less aggregate - meaning: quicker installation. So not only does the Combigrid® reinforcement yield savings in the long-term performance and integrity of the roadway, it saves cost during the construction or rehabilitation phase of the road.

Also of note, Combigrid®'s 4.75m wide rolls mean significant coverage can be achieved quickly with less need for roll cutting (reduced on-site waste of materials and quicker installation). The robustness of the material (See Lesson 4) helps prevent damage during installation. And the high quality of Combigrid®'s production means the product that arrives on site is the product specified. Combigrid® is manufactured in an ISO 9001-audited facility and is supported by a round-the-clock staffed, stringent manufacturing quality control program and a state-of-the-art materials testing laboratory.

Combigrid® is engineered to perform a significant, multi-functional role for roadway and railway reinforcement, embankment reinforcement, load transfer platforms over pile caps, and other key base reinforcement applications. And it's engineered to do so in an economical, efficient manner from the moment the installation work begins.

Fig. 17 *Estimated loss of aggregate due to subsoil intermixing if no separation geotextile is used (Source: Task Force 25 Report, 1989, Highway Administration, FHWA)*



LESSON #9:
Learn from Experience

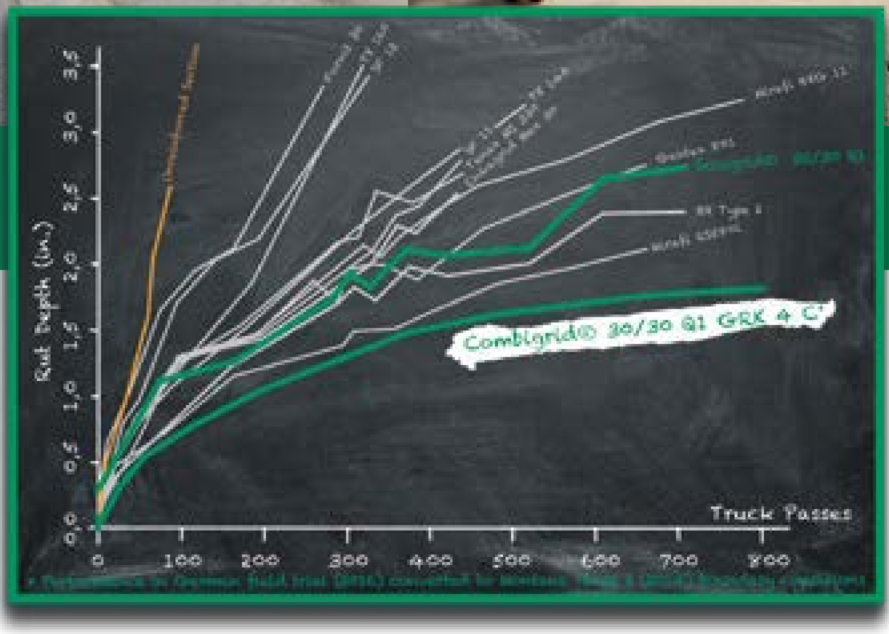


Fig. 19
Comparison of Montana (Phase 2, 2014) field trial results with Combigrid performance from German field trial (2016)

Large-Scale-Field Trial

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. 18) 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.

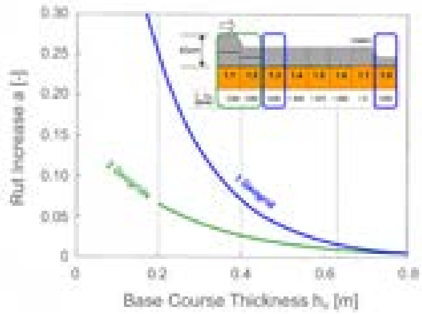
Performance Results

Figure 18 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 20 shows the ***clear benefit of geogrid tensile stiffness $J_{2\%}$*** to reduce rut deformation for all sections with equivalent base course thickness.

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 wovens, 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 our biaxial laid and welded geogrid Secugrid® 30/30 Q1. 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 GRK 4 C (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 GRK 4 C 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. 19) shows a clear advantage for ***Combigrid® 30/30 Q1 GRK 4 C and its unique multifunctional benefit: stabilisation, reinforcement separation and filtration in one product!***

Fig. 18
Rut increase vs. base course thickness h_0 for sections with same geogrid tensile stiffness $J_{2\%}$



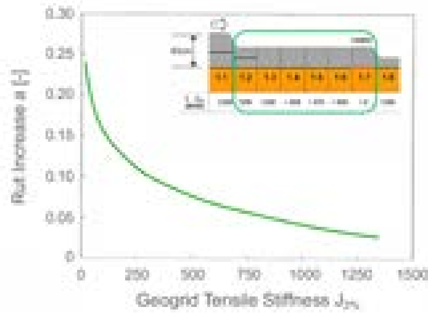


Fig. 20
Rut increase vs. geogrid tensile stiffness $J_{2\%}$ for sections with same base course thickness



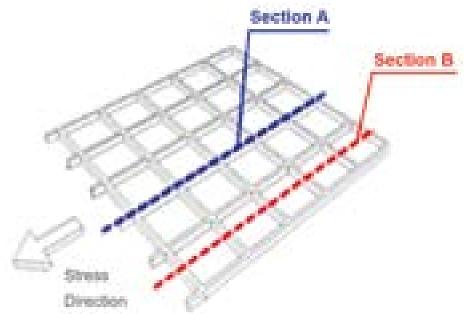
LESSON #10:
Prevent slippage

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 21, Section A)
- the passive resistance mobilized against the bearing members/bars (Figure 21, 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)

Fig. 21
Interaction mechanisms of geogrids



To optimize interface friction between soil and the solid area of the reinforcement (bearing surface), the geogrid component of Combigrid® has an embossed surface on both sides. Especially with fine grained subgrade soils, like silts or clays the "surface roughness" of the geogrid bars increases the shear resistance against the in-situ subgrade soil and provides resistance against lateral soil movement. 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. The imprint of the geogrid embossing into the soft ground demonstrates the good frictional interaction.

The poorer the aggregate quality, i.e., the finer the grading, the more important becomes the frictional interaction. With its embossed surface structure, Secugrid® & Combigrid® stabilisation and reinforcement products widen the range of applicable aggregate materials.

Performance Results

Fig. 22
Comparison of rut depth at 300 truck passes, Montana field trial (Phase 2, 2014)

Figure 22 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 Montana, USA, in 2014. 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 23), 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 multi-directional 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" as friction characteristic 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.

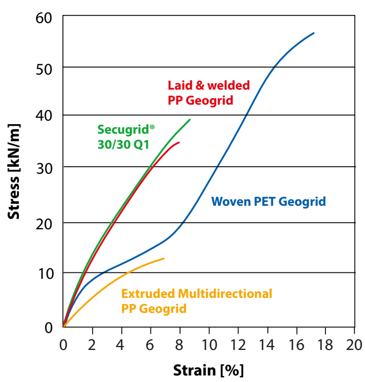


Fig. 23
Stress-Strain curves of 4 tested geogrids in Montana field trial (Phase 2, 2014)




Geosynthetics have transformed construction and geotechnical engineering in the last 50 years due to their innovative use of polymers to create effective and economic materials with application-specific functions, service lives, and performance characteristics. Secugrid® geogrids have enabled taller/steeper walls, stronger roads, and more sustainable and economical developments. Today, the combination of geogrids and geotextiles into a single-roll Combigrid® composite reinforcement product has greatly enhanced these beneficial impacts. This is the next generation of soil reinforcement. The characteristics (or, lessons) that define the use and success of Combigrid® multi-functional reinforcement materials are easy to understand: higher strength, higher factors of safety, better performance, better project economics, and more sustainable infrastructures. This is not a matter of "black box" engineering; it is clear, old-fashioned blackboard engineering.

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