Geocomposites for the improvement of long term trafficability

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ABSTRACT
Due to the globalization of the world economy existing ports are being developed and new ports are being built in order to cope with the increasing volume of goods in transit. New container terminals or port extensions are mostly built on reclaimed land from the sea. Often the existing subsoil's not provide sufficient bearing capacity to take up the final loads of the container terminals, the long-term stability and trafficability of the gained land must be improved. An economic measure to improve the bearing capacity of existing and newly developed terminal areas is the use of geogrid/nonwoven composite material as reinforcement and separation layers. As the geogrid can absorb greater tensile stresses than the base course itself, the tension in the reinforced base course is reduced. This leads to a more efficient load distribution within the base course and thus to less vertical deformation (settlement and rutting) at the pavement surface, which thus significantly increases the serviceability of these intensively used traffic areas.

As shown in laboratory tests, a geogrid/nonwoven geotextile composite material can provide a tremendous increase in long-term trafficability compared to areas without reinforcement or only with the use of normal geogrids. This paper will give an overview on the state-of-the-art using geogrid/nonwoven composite materials to increase the bearing capacity of the base course.

ABSTRACT
L'un des effets de la mondialisation de l'économie est le développement des ports actuels et la création de nouveaux ports afin de faire face à la croissance constante du volume de marchandises en transit.

Les nouveaux terminaux à conteneurs ou les agrandissements des ports sont la plupart du temps construits sur des terrains gagnés sur la mer. Étant donné que les remblais, du fait de leur compacité faible ou moyenne, ont une force portante insuffisante pour résister à la charge finale des terminaux à conteneurs, il est nécessaire d'améliorer la stabilité et l'aptitude à la circulation à long terme.

Une mesure économique retenue pour améliorer la force portante des terrains des terminaux actuels et futurs consiste à utiliser des renforts à base de géogrilles ou de géogrilles composites (de type Combigrid®) sous forme de couches de séparation et de renfort. Comme la géogrille peut accepter des contraintes de traction plus élevées que la propre couche de base, les contraintes appliquées à cette dernière sont fortement réduites. Il en résulte une distribution plus efficace de la charge dans la couche de base et donc une moindre déformation verticale (affaissement et orniérage) au niveau de la surface de circulation des terminaux. Résultat : l'état de viabilité de ces zones de circulation utilisées de façon intensive s'en trouve clairement amélioré.

Comme le mettent en évidence les essais sur site et en laboratoire, une structure composite de type géogrille / non-tissé permet d'obtenir une amélioration considérable de l'aptitude à la circulation à long terme par comparaison aux zones non renforcées (5000 fois plus) ou utilisant des géogrilles normales (100 fois plus).

Cet article donnera une vue d'ensemble de l'état de la technique utilisant des matériaux composites de type géogrilles / non-tissés, parfois combinés avec une deuxième couche de géogrille de renfort, pour augmenter la force portante de la couche de base dans divers projets internationaux de ports, par exemple en Allemagne, Turquie, Oman et aux États-Unis.

1. INTRODUCTION

1.1 General

Container storage areas carry large traffic volumes and typically have concrete or paved surfacing over a base layer of aggregate. The combined surface and base layers act together to support and distribute traffic loading to the subgrade. Problems are usually encountered when the subgrade consists of soft clays, silts and organic soils. These types of soils are often water sensitive and, when wet, unable to adequately support traffic loads. If unimproved, the subgrade will mix with the road base aggregate, which leads to a reduction of strength, stiffness and drainage characteristics, promoting distress and early failure of the roadway. This mixing of the base aggregate with the fine grain materials can also lead to an increase of frost heaving.

1.2 Separation of Subgrade and base course

A geotextile which is placed between the subgrade and the base course layer provides physical separation of subgrade and base materials during construction and during operating life of the trafficked area.
(see Figure 1).

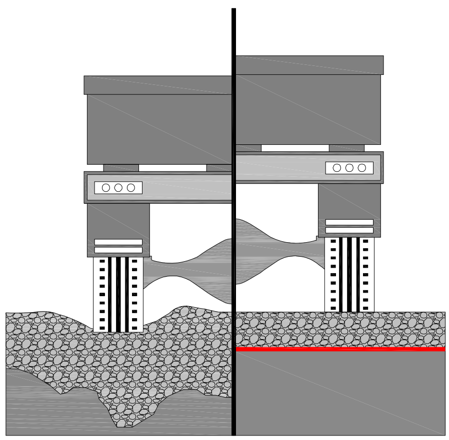


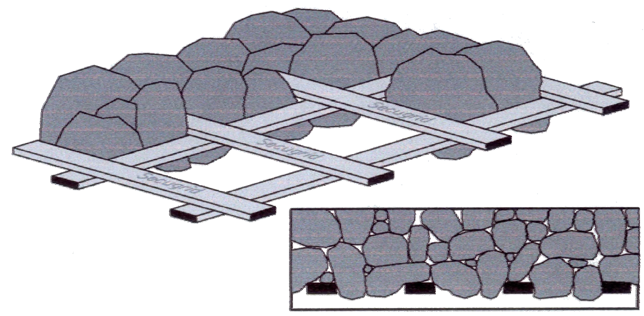
Figure 1. Illustration of geotextile separation function

The separation function of the geotextile is defined by a prevention of mixing, where mixing is caused by mechanical actions. The mechanical actions generally arise from physical forces imposed by construction or operating traffic and may cause the aggregate to be pushed down into the soft subgrade and / or the subgrade to be squeezed up into the base aggregate. A properly designed geotextile separator allows the base aggregate to remain "clean", which preserves its strength and drainage characteristics. The use of geotextile separators ensures that the base course layer in its entirety will contribute and continue to contribute its structural support of vehicular loads; the separator itself is not viewed to contribute structural support to the aggregate layer. Yoder and Witczak (1975) 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 highlights the importance of a geotextile separator with regard to the performance of base aggregate layers on fine-grained subgrades.

1.3 Reinforcement of base courses using geogrid reinforcement

Vehicular loads applied to the surface of trafficked areas create a lateral spreading motion of the unbound aggregate layers. Tensile lateral strains are created at the interface subgrade/geogrid as the aggregate moves down and sideways due to the applied load. Through shear interaction of the base aggregate with the gegrid, a.k.a. inter-locking, (see Figure 2), the aggregate is laterally restrained or confined (see Figure 3) and tensile forces are transmitted from the aggregate to the geogrid.

Figure 2. Interaction of aggregate with geogrid

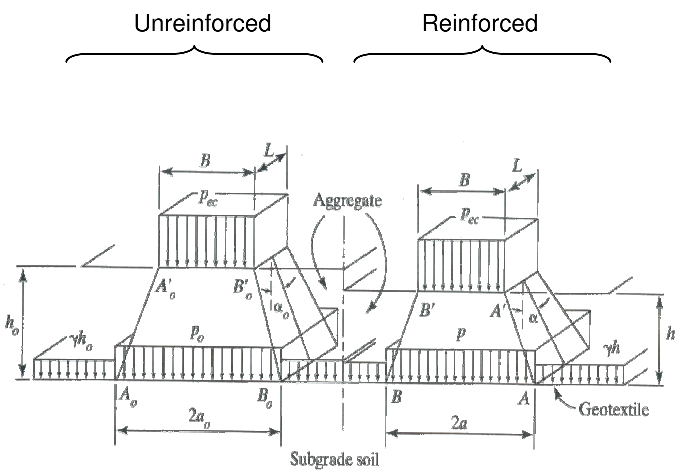


As the geogrid is much stiffer in tension as the aggregate itself, the lateral stress is reduced in the reinforced base aggregate and less vertical deformation at the road surface can be expected. This interaction between geogrid and base course material increases the shear strength and thus the load distribution capacity of the used base course material.

Figure 3. Lateral restraint of aggregate using high modulus laid and welded geogrids

The increased load distribution capacity reduces vertical stresses on the subgrade, which finally reduces the deformation (rutting) on the surface of the aggregate layer. This correlation enables the reduction of reinforced base course thicknesses in comparison to un-reinforced layers (see Figure 4).

Figure 4. Increase of load distribution capacity with the use of geogrids (Koerner 1998)



In many projects, good quality base course aggregate is not available on site or close to the site. As a result, high transport costs of imported, expensive good quality base aggregate have a great influence on the total project costs. Especially under those conditions geosynthetic reinforcement and separation products can help to save money by reducing the amount of imported fill material needed to achieve the specified bearing capacity for the expected loads on the base course.

To combine the function of reinforcement and separation in one product, so called Geocomposites have been developed. Geocomposites as e.g. Combigrid® (see Figure 5) allow faster construction rates compared to separately installed geogrid and geotextile components.

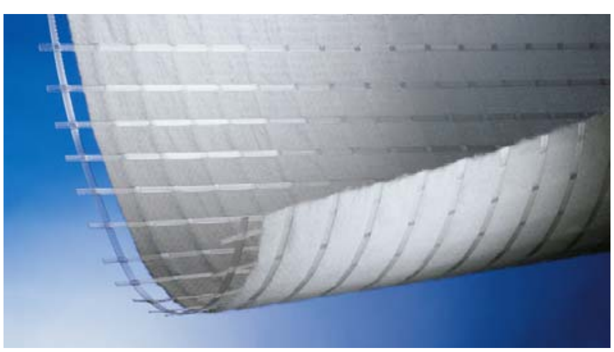


Figure 5. Combigrid® Geocomposite (geogrid reinforcement & needle punched nonwoven geotextile, firmly bonded between the cross laid reinforcement bars)

2. PERFORMANCE OF BASE REINFORCEMENT GEOGRIDS IN ROADWAY STABILIZATION APPLICATIONS

2.1 Large Scale Laboratory Test

The purpose of the study was to evaluate the reinforcement benefit provided by different geogrids. Benefit was defined in terms of the number of load cycles to reach a specific permanent rut depth of 3 inches in the aggregate surface layer for each section and Traffic Benefit Ratio (TBR), which is the number of load cycles for a reinforced section divided by the number of load cycles to reach this same rut depth for a comparable unreinforced test section. The test sections were instrumented to measure geosynthetic deformation and subgrade pore water pressure response.

The pavement test box facility used for the laboratory test was designed and constructed for the purpose of conducting laboratory, full-scale experiments on reinforced and unreinforced pavement sections and it meets the requirements of specifications developed for AASHTO Subcommittee 4E as contained in Berg et al., 2000. The test box facility is designed to mimic pavement layer materials, geometry and loading conditions encountered in the field as realistically as possible with an indoor, laboratory based facility. This type of test box facility allows a high degree of control to be exercised on the construction and control of pavement layer material properties.

Each roadway test section was constructed with a nominal cross-section consisting of 12 in. (300 mm) of base course aggregate and 40 in. (1.1 m) of subgrade soil with a CBR = 1. The geosynthetic was placed between the base course and subgrade layers. A control test section having the same cross section without a geogrid was used for comparison to the geogrid stabilized sections. A cyclic, non-moving load with a peak load value of 9 kips (40kN) was used to mimic dynamic wheel loads. Sensors were used to measure applied pavement load, pavement surface deformation, and stress and strain in the base aggregate and subgrade soils. At a later state, the results of the dynamic plate loading laboratory tests shall be compared to results from test sections in the field, where moving wheel loads (three axle dump truck) are used to generate the pre-defined deformation rates. In both, the laboratory and the field test, the boundary conditions of the prepared subgrade and base course (as e.g. type, moisture content, gradation & angularity of base) are comparable.
Amongst others, the results shall be used to quantify the influence of circular (plate load) versus biaxial loading (wheel load) on the development of rut deformation.

2.2 Test-Box and Loading Apparatus

Test sections were constructed in a 6.5 ft (2 m) by 6.5 ft (2 m) by 5 ft (1.5 m) deep box shown in Figure 6. The walls of the box consist of 6 inch (150 mm) thick reinforced concrete. The front wall is removable in order to facilitate excavation of the test sections.

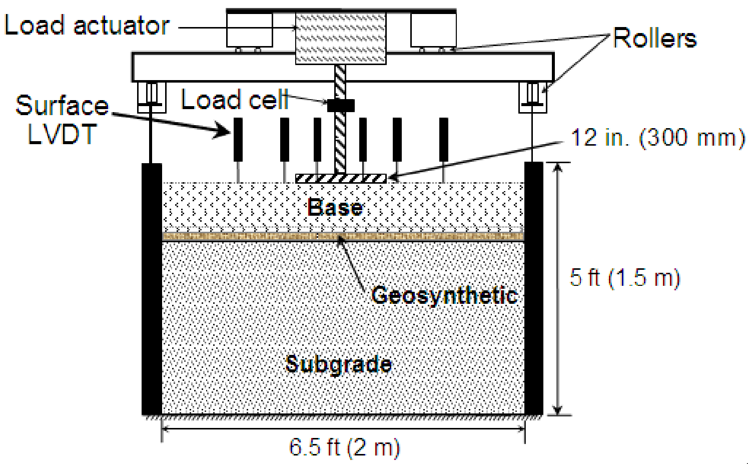


Figure 6. Schematic diagram of the pavement test facility

I-beams set into two of the concrete walls serve as a base for the loading frame. The load frame consists of two additional I-beams that span and react against the I-beams set into the concrete walls of the box. A load actuator, consisting of a pneumatic cylinder with a 12-in. (300-mm) diameter bore and a stroke of 3 in. (75 mm), is placed between the two I-beams of the frame. A 2-in. (50-mm) diameter steel rod extends from the piston of the actuator. The rod is rounded at its tip and fits into a cup welded on top of the load plate that rests on the pavement surface.

The load plate consists of a 12-in. (300-mm) diameter steel plate with a thickness of 1 in. (25 mm). A ¼-inch (6.4 mm) thick, waffled butyl-rubber pad is placed beneath the load plate in order to provide a uniform pressure and avoid stress concentrations along the plate's perimeter. Figure 2 shows an image of the load plate resting on the pavement surface. A binary solenoid regulator attached to a computer controls the load-time history applied to the plate. The software controlling the solenoid is the same software used to collect data from the pavement sensors. The software is set up to provide a linear load increase from zero to 9 kips (20 kN) over a 0.3 second rise time, followed by a 0.2 second period where the load is held constant, followed by a load decrease to zero over a 0.3 second period and finally followed by a 0.5 second period of zero load before the load cycle is repeated, resulting in a load pulse frequency of 0.67 Hz. The maximum applied load of 9 kips (40 kN) resulted in a pavement pressure of 80 psi (550 kPa). This load represents one-half of an axle load from an equivalent single axle load (ESAL).

Instrumentation was included in each test section. The instrumentation is designed to evaluate rutting in the stabilization aggregate, strain distribution in the reinforcement with distance away from the wheel load, and pore water pressure response of the subgrade during placement, compaction and subsequent loading. Instrumentation was included to make the following measurements:

1. Vertical surface deformation in the stabilization aggregate layer.
2. Applied load to the plate using a calibrated load cell.
3. Pore pressure in the subgrade during construction and pavement loading.
4. The geosynthetics were instrumented with wire extensometers, which were connected to LVDTs to measure the transfer of stress away from the wheel loading area.
5. The geosynthetics were extended through the front of the test box and visually monitored to determine if any movement was occurring at the edge of the box during application of the load.

2.3 Geosynthetic Materials

The geosynthetic materials used in these tests were a welded polypropylene biaxial geogrid and a composite geogrid using a welded polypropylene biaxial geogrid where a needle punched nonwoven geotextile is firmly bonded between the cross laid reinforcement bars. Tests were also performed with the welded polypropylene geogrid placed directly over a needlepunched nonwoven polypropylene separation geotextile (NP NW GTX). The used geotextile had a mass per unit area of 4.5 oz/yd^2 (150 g/m^2). The relevant properties of the used materials are shown in Table 1.

Table 1. Geogrid characteristics

Properties	Laid and welded PP geogrid (30 kN/m) (LW GG30)	Laid and welded PP geogrid (60 kN/m) (LW GG60)	Geocomposite material of laid and welded PP geogrid (30 kN/m) + PP nonwoven GTX (GC GG30)

T_{ult} MD lb/ft (kN/m)	2055 (30)	3080 (60)	2060 (30)
T_{ult} XD lb/ft (kN/m)	2055 (30)	3080 (60)	2060 (30)
$T_{2\%}$ MD lb/ft (kN/m)	686 (10)	1850 (36)	690 (10)
$T_{2\%}$ XD lb/ft (kN/m)	686 (10)	1850 (36)	690 (10)

2.4 Subgrade soil

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Piedmont silt (ML-MH) from Georgia was used for the subgrade. The residual soil was selected based on its problematic construction characteristics that include for instance pumping effect at near optimum moisture contents, which usually requires chemical or mechanical stabilization, especially when wet of optimum (as is most often the case). Residual soils tend to retain the parent rock structure (e.g., joints and fractures) with additional fractures occurring due to stress relief during excavation. Excess water collected in this structure results in high sensitivity when disturbed. These soils are also often characterized by a relatively fast dissipation of pore water pressure as opposed to more cohesive soils.

The gradation tests (ASTM 422 and ASTM 1140) indicate that the soil is micaeous sandy silt (ML-MH) with 95% passing a 1mm sieve and 65% passing a 0.075 mm sieve. The soil has a maximum dry unit weight of about 109 lb/ft^3 (15.2 kN/m^3) at an optimum moisture content of 17%.

2.5 Base Course Aggregate

The base course material used in all test section was a graded aggregate base meeting the Georgia Department of Transportation specifications. Standard Proctor compaction test (ASTM D 698) and gradation tests were performed on the aggregate base course and the results are also included in Appendix A. The aggregate has a maximum dry density of about 145 lb/ft^3 (22.8 kN/m^3) at an optimum moisture content of 5.4%. The graded aggregate base was estimated to have a friction angle of 43° based on large direct shear tests that have been previously performed on similar materials at Geo Testing Express Laboratory.

2.6 Test Results

The primary results of the stabilization test are in terms of the deformation response of the aggregate layer. Figure 7 provides a summary of the permanent deformation response for all test sections constructed with 12 inches of aggregate and a CBR = 1%. Table 2 provides a comparison of the performance characteristics from each test section, including the number of cycles and the corresponding Traffic Benefit Ratio (TBR) for each of the test result at 1 inch (25 mm) and 3 inch (75 mm) of rutting. Rut depths between 1 and 3 inch are acceptable deformation rates for unpaved roads but not for paved roads.

The results clearly show a difference in the performance of the geosynthetics evaluated in the study. The Geocomposite material (laid and welded geogrid (30 kN/m) + nonwoven needle punched geotextile firmly bonded between the cross laid reinforcement bars) performed the best of all materials tested and reached over 850 cycles of loading before reaching 3 in. (76 mm) of rutting and had a TBR value of over 170. Over 10,000 cycles were required to reach a rut depth of 4 in. (100 mm). Open geogrids may be at a disadvantage with the type of soil used, as no filter stability between the coarse aggregate and the fine grained subgrade is given, so that the soft subgrade can easily be penetrated by gravel particles from the base course layer until interlock is developed. Regardless, both laid and welded geogrids provided significant improvements in deformation response over the control section with TBR values between 11 and 19.

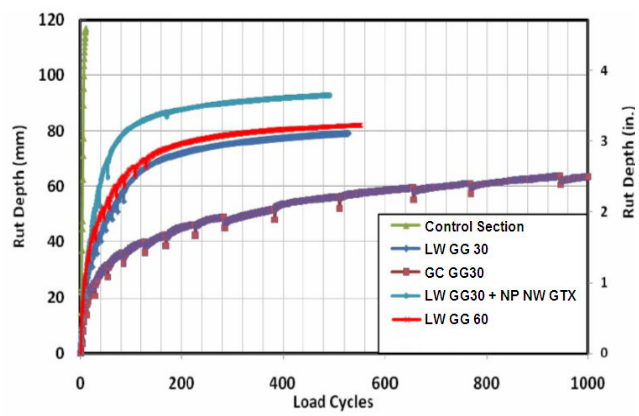

Figure 7. Permanent Deformation Response versus Load Cycles for CBR = 1 Subgrade

Table 2. Performance Characteristics (TBR) of each Test Section

Section	Number of Cycles		Traffic Benefit Ratio (TBR)	
	1-in. (25mm) rut	3-in. (75mm) rut	1-in. (25mm) rut	3-in. (75mm) rut
Control	1.5	5	1	1
LW GG30	4.5	97	3	19.4
LW GG 60	1.5	55	1	11

GC GG30	6.5	855	4.3	171
LW GG30 + NP NW GTX	1.2	31	0.8	6.2

Much of the difference between the two laid and welded geogrids with 30 kN/m and 60 kN/m (LW GG30 & LW GG60) tensile strength can be attributed to the differences in the first few load cycles which are applied at the beginning of the test. As it is not possible to maintain a consistent loading during the application of the first few load cycles movement occurs due to shoving and displacement of aggregate during interlock. In stabilization research performed by the US Army Corps of Engineers, these cycles are referred to as "initial seating" (Tingle and Jersey, 2005) and they are removed from the data. If this procedure is followed and the first 3 cycles are removed, the hierarchy of the data remains the same, however then the deformation response of the 60 kN/m laid and welded geogrid is slightly better (less rutting) compared to the 30 kN/m laid and welded geogrid. The laid and welded geogrid placed over the nonwoven needle punched geotextile (LW GG30 + NP NW GTX). The higher deformation response of the separately installed components is attributed to sliding of the geogrid over the nonwoven geotextile.

A summary of the pore pressure response of each test section is shown in Figure 8. The pore pressure directly corresponds to the results in Figure 7 with the high initial pore pressure developing for test sections where the largest amount of deformation per cycle was measured. The pore water pressure results indicate the disturbance due to aggregate penetration into the subgrade in the control section and the open geogrid section, which leads to high pore water pressure. The increase in pore water pressure reduces the effective strength of the soil, resulting in an undrained subgrade strength that is actually less than CBR = 1% and correspondingly increased rutting occurs. This rapid pore pressure build up does not occur in the Geocomposite (GC GG30) due to the separation provided by the geotextile

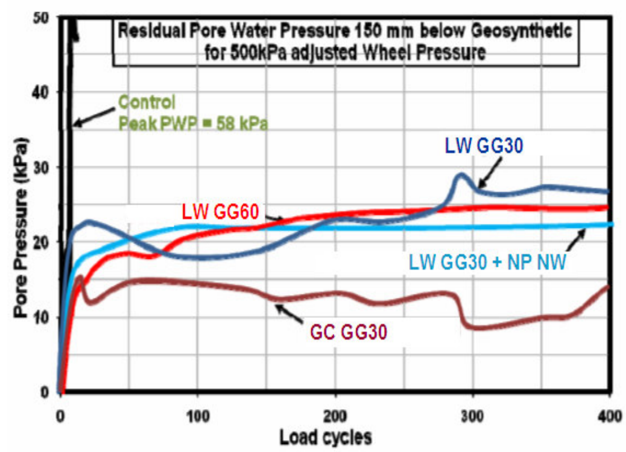

Figure 8. Pore pressure in Subgrade versus Load Cycles for CBR = 1 Subgrade

1 CONCLUSION

The increase of global trade and transport of goods creates growing demands to handle cargo. To accommodate growing cargo volumes, existing ports are extended and new ports are being built. Soft subgrades are often the basis for the foundation works of new container terminal's pavement systems. As economic construction method geogrids are often used in this case to improve the insufficient bearing capacity for the expected traffic and storage loads. Geogrids first of all allow and secondly improve the compaction of foundation layers on soft soils. The technology of geosynthetic reinforced aggregate layers provides an economic construction method for the development of new container terminals.

With the improved structural load-bearing capacity of geogrid reinforced aggregate layers, stress concentrations on soft subrades can be reduced, which minimizes differential settlements at the pavement surface and automatically improves the transport safety of container-handling equipment.

Increasingly so called "Geocomposite" materials are used which consist of a nonwoven geotextile component and a geogrid reinforcement layer. The geotextile with its separation and filtration function ensures that the base course layer in its entirety will contribute and continue to contribute its structural support of vehicular loads as it prevents the aggregate to be pushed down into the soft subgrade and / or the subgrade to be squeezed up into the base aggregate. The geogrid increases the shear strength and thus the load distribution capacity of the used base course material.

Latest test results from large-scale laboratory testing, which has been presented in this paper, shows the outstanding performance of a specially developed geosynthetic composite material (a welded polypropylene biaxial geogrid with a needle punched nonwoven geotextile firmly bonded between the cross laid reinforcement bars) against individually installed geogrid reinforcement layers or separately installed combinations of geogrid reinforcement and geotextile separators.

The use of the described composite geosynthetic reinforcement in subgrade stabilization projects enables savings with regard to required installation time when compared to separately installed geotextile separator and geogrid components. Secondly a reduction of base course thickness can be achieved compared to unreinforced sections, because of the improved load distribution capacity which is achieved with the use of composite geosynthetic reinforcement. Besides the economical aspect, also the ecological aspect needs to be highlighted. As "good quality" aggregate is often not available close to the construction site or not in the required quantity, the possible reduction of base course thickness with the use of composite geosynthetic reinforcement reduces transport costs and the consequential environmental impact.

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