Geogrid Reinforced Subgrade Influence to Ensure Paved Road Durability

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Abstract. Geosynthetic materials are more and more often used for subgrade reinforcement and/or stabilisation. Geosynthetic reinforcement products used for paved and unpaved roads or traffic areas function on the basis of two mechanisms that contribute to their performance. Shear loads developing in unbound granular layers as a result of traffic loading are transmitted from the base aggregate to the geosynthetic as a result of frictional interaction or via the so called interlocking effect. Depending on the geosynthetic material properties load absorption functions on the basis of frictional interaction and the membrane effect. This study indicates how these two load absorbing mechanisms, depending on the geosynthetic material properties, correspond to the regulations for use of geosynthetics for road embankments and subgrades and harmonised European standards that are valid in Lithuania. It also presents the corrections and additions to improve the existing regulations for use of geosynthetics for road embankments and subgrades to ensure a better paved road durability.

Keywords: regulations, stabilisation, reinforcement, geogrids, durability, installation damage.
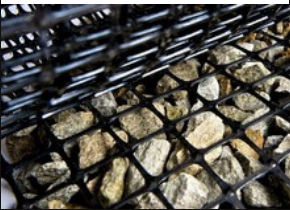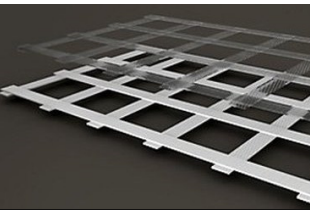
Conference topic: Roads and railways.

Introduction

Since geosynthetic products have successfully been used in the wide field of civil engineering applications over the last decades, the following main functions have been defined and considered in the international documentation: Separation, filtration, barrier, drainage and reinforcement (Vaitkus 2010). When reinforcement products, especially geogrids, are used to improve road base courses, the reinforcing effect includes the interlocking between geogrids and granular materials which is utilized to provide adequate lateral restraint. This leads to a stiffer base course and less deformations due to reduced or prevented movement of particles in the granular layer 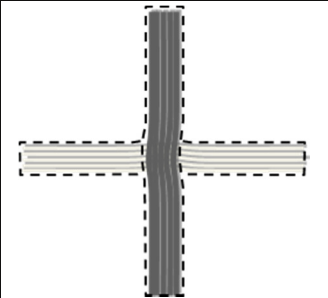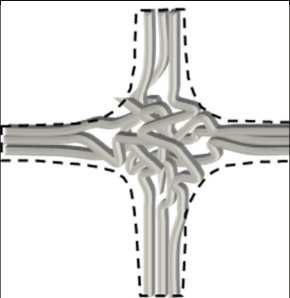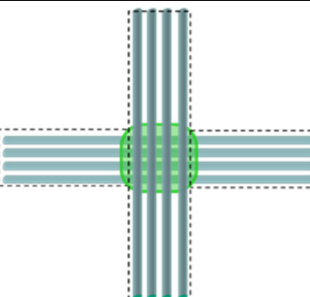under the influence of dynamic loading. The lateral restraint effect is also called stabilisation (Psiorz, Klompmaker 2014). Subgrade stabilization allows a firm construction platform to be built with less aggregate and less construction time as compared to construction without the geogrid stabilization. It is generally known that the tensile strength and elongation of the geogrid as well as its interaction with the soil is of fundamental importance for the performance of geosynthetic reinforced base courses (Al-Qadi *et al.* 2011). Whereas the strength and elongation of products can be measured uniaxially and multiaxially and can be described by linear and bilinear functions (Vollmert *et al.* 2016). There is a general consensus concerning the effectiveness of geosynthetics in this application. However, there is a lack of understanding and agreement on which geosynthetic material properties best relate to their performance. Those properties should be specified or used in design to ensure its beneficial use and to allow a broad range of products to be considered (Cuelho, Perkins 2016). Also, the reinforcement effect has two phases – interlocking effect and membrane effect. The interlocking effect describes the bond between the geogrid and the soil, the membrane effect the absorption of tensile stresses by the reinforcement. Each effect, considered on its own, can exert neither a stabilising influence on the soil skeleton nor a reinforcing influence and neither effect occurs singly, but both overlap each other (Vollmert *et al.* 2014). Before the reinforcement can absorb the developed stresses in the granular layer, tensile strength needs to be activated which is always linked to an accumulation of strain. A geogrid without appropriate strength at low strain levels cannot provide stabilization effect (Psiorz, Klompmaker 2014). This leads to a question of what geogrid properties show the biggest effect on reinforcement and are there any of them described and/or evaluated in an existing normative documentation.

Geogrid types

There are three types of geogrid existing nowadays. Those types are defined by the manufacturing process of geogrid, described in Table 1. Each type of geogrid can be manufactured using different types of polymers: polypropylene, polyester, polyvinyl alcohol, polyethylene, aramid and polyamide. Some woven or knitted geogrids can be additionally covered with protective PVC layer.

Table 1. Geogrid types

	Woven or knitted geogrids	Extruded geogrids	Laid geogrids
Geogrid type			
Junction			
Molecule orientation			
Installation damage coefficient	1.10-1.25	1.10-1.20	1.00-1.10

Although all types of geogrids can have similar tensile strength and elongation parameters, the performance in real conditions can be quite different. Woven geogrids are manufactured through interlacing, usually at right angles, two or more yarns or filaments. Geogrid is additionally coated with polymer or nontoxic substance material for better UV, acid and alkali resistance. Woven geogrids are flexible, junctions are not stiff. Usually they have lowest resistance to the installation damage compared to laid geogrids (Rüegger, Hufenus 2003). Due to the geogrid flexibility, the tensile stiffness at low strain has the lowest values. Extruded and laid geogrids are not coated with other polymers, they are both rigid and have stiff junctions, but the difference between them is the surface area and junction itself. Where extruded geogrids have nonlinear molecule distribution between bars and junctions, but have monolithic junction, laid geogrids have uniform molecule distribution but have welded junction. Comparing the installation damage it has to be mentioned that welded geogrids in general have better resistance to installation damage, compared to extruded geogrids and if the junction broke, the damage do not transfer to the bar and other junctions. The extruded geogrid has a tendency to crack further along the bars when the junction breaks. However, laid geogrids has to be installed more carefully, because welded junctions can break before the installation if junction is pulled apart. The tensile stiffness at low strain of laid geogrids in general is also slightly bigger compared to extruded ones.

Subgrade reinforcement and stabilisation

At first, it is a crucial thing to clarify what is subgrade reinforcement and what is soil stabilization. At the moment, no existing European standard or any design guidelines for roads clearly explain those terms and the relation between them. Therefore we have lots of misunderstanding in the design of how the geogrid effects paved road construction, its durability and what parameters of geogrid we should evaluate on doing the design. Berg *et al.* (2000) categorise the function of geosynthetic reinforcement products as either base/subbase reinforcement or as subgrade restraint/stabilization. Base/subbase reinforcement is typically applied to support vehicular traffic over the life of a pavement structure. Subgrade restraint/stabilization is the use of a geogrid placed at the subgrade/subbase to increase the support of construction equipment over a week or soft subgrade. The primary mechanism with this application is increased bearing capacity although lateral restraint and/or tension membrane effects may also contribute to load-carrying (Psiorz, Klompmaker 2014). The geogrid reinforcement mechanisms have been defined by Haliburton *et al*. (1981): lateral restraint, which consists of lateral restraint of aggregate movement, base aggregate modulus increase, improved vertical

stress distribution on subgrade and reduced shear strain along the top of the subgrade; bearing capacity increase; tensile membrane support – mobilised under high deformation conditions. The term stabilization is primarily used in the case that the in-situ soft subgrade does not provide adequate bearing capacity to support construction equipment. In this case a working platform is required, which is stabilized using geogrid reinforcement. The term reinforcement is used when the geogrid has to support vehicular traffic over the life of a pavement structure. Subgrade increase of bearing capacity on soft soil is the reinforcing component of stabilization (Berg *et al.* 2000). The stabilization effect of granular layers with geogrid is reducing with increasing of the flexibility of the applied reinforcement product. The precondition for a geogrid to allow for stabilization to take place is the existence of geometrically defined openings, which allow partial penetration of aggregate particles and thus facilitate a stabilization or lateral restraint effect by the surrounding tensile members (Psiorz, Klompmaker 2014). When the traffic loading is applied on the road construction, the granular material is stressed and it transfers the stresses either to the subgrade or to a geogrid, which is installed between sub-grade and granular layer (Žiliūtė *et al.* 2010). On soft soils, the first would lead to a heavily increased road pavement deformations, therefore a used geogrid reinforcement could reduce the shear strain in the soft subgrade. To absorb the acting stresses in the aggregate, the reinforcement tensile strength has to be activated and this always leads to an accumulation of strain. A geogrid without appropriate strength at low strain levels cannot provide this effect. In other words, insufficient strength at low strain means no stabilization and this leads to no reinforcement. Stabilization is required to efficiently transfer the stresses from the soil to the geogrid. The generated vertical and horizontal stresses in the aggregate layer together with the stabilization effect of the geogrid, automatically initiates the development of tensile forces by the reinforcement at low strains. This is a combined effect, where stabilization can be understood as initial status of the reinforcing mechanism pronounced at low deformation state, linked to enhanced serviceability (Vaitkus *et al.* 2007). The geogrid is much stiffer in tension than the aggregate and because of that the lateral stress is reduced in the reinforced aggregate layer and this leads to less vertical deformation at the surface. The enhanced rein-forcing effect by stabilization is reducing the effect of a progressive deterioration of the aggregate layer (Psiorz, Klomp-maker 2014).

Field trials

A number of large-scale trafficking trials were performed in Europe and United States of America to identify what geogrid parameters have the biggest influence on the road durability. These tests were carried out to determine geogrid properties that are most related to the in-field performance used to subgrade stabilization, so that designers could objectively specify appropriate geogrids based on material properties and allowing competition from different manu-facturers. When lots of tests performed earlier had one or another issue that did not allowed to clearly compare geo-synthetic reinforcing products, Cuelho and Perkins (2009) reported on a first series of highly sophisticated on-site trials for subgrade stabilization in Montana.

Montana State University did a large-scale field trials that started with Phase I with the test report on 2009 and finished with Phase II with test report on 2014. They constructed test sections at a controlled test site to investigate the relative benefit to an unpaved road of various geosynthetics available on the market at the time. A subgrade soil was constructed in a week state to provide equivalent conditions for each test section. The gravel surfacing along the entire test bed was uniformly constructed to be able to make direct comparisons between geosynthetic products. Longitudinal rut from traffic loading was the primary indicator of performance benefits of each geosynthetic material. Material properties, which were tested in a laboratory, were used in a regression analysis to determine their relationship to the performance in this application.

The research project was specifically planned to quantify differences in performance of various geosynthetic products under the same conditions. In addition, supplemental test sections were constructed to study the effect that variations in subgrade strength and base course thickness had on the performance. The final arrangement of the test sections is shown in Figure 1, which includes the target subgrade strength and base thickness properties for construc-tion. Each test section was 4.9 m wide and 15 m long. Ten geogrids were used in this research project. Five laboratory tests were used to characterize the geosynthetics used in this research, including wide-width tensile strength, cyclic tensile modulus, resilient interface shear stiffness, junction strength and aperture stability modulus.

Trafficking was accomplished using a three-axle dump truck that weighed 20.6 tons. Trafficking was always in one direction and the speed was approximately 8 km/h to ensure that dynamic loads were not induced. Trafficking was applied until rut depth reached 75 mm and this was defined as failure point for the section. An empirical correction procedure was implemented to adjust the rut response for subgrade strength and base course thickness so that direct performance compari-sons between test sections were more accurate.

The test showed that in situations where there is less structural benefit from the gravel base course layer and more benefit is expected of the geosynthetic, stiffness and tensile strength play a greater role in rut suppression, especially given the rapid deterioration of these test sections under traffic load. The strength and stiffness of the junctions in the cross-machine direction plays a role, but diminishes as rut develops. Conversely, in situations where there is more base course and rut development is less rapid, the role of junction stiffness and strength is more apparent as reliance on this property for perfor-mance increases as a function of rut. Coupled with this is the early dependence on the stiffness of the geogrid as loads are

transmitted into the material as the geogrid confines the base aggregate as it spreads laterally under the applied load. Once the material has been engaged in this way, further transmission of lateral loads are borne by members in the machine direction of the material as they transmit the load into the cross-machine load bearing members. The geogrids that performed the best were rigid, had stiff junctions and enough tensile strength. The geogrids that have good junction strength but low tensile strength or high tensile strength but low junction strength did not perform well (Cuelho, Perkins 2016).
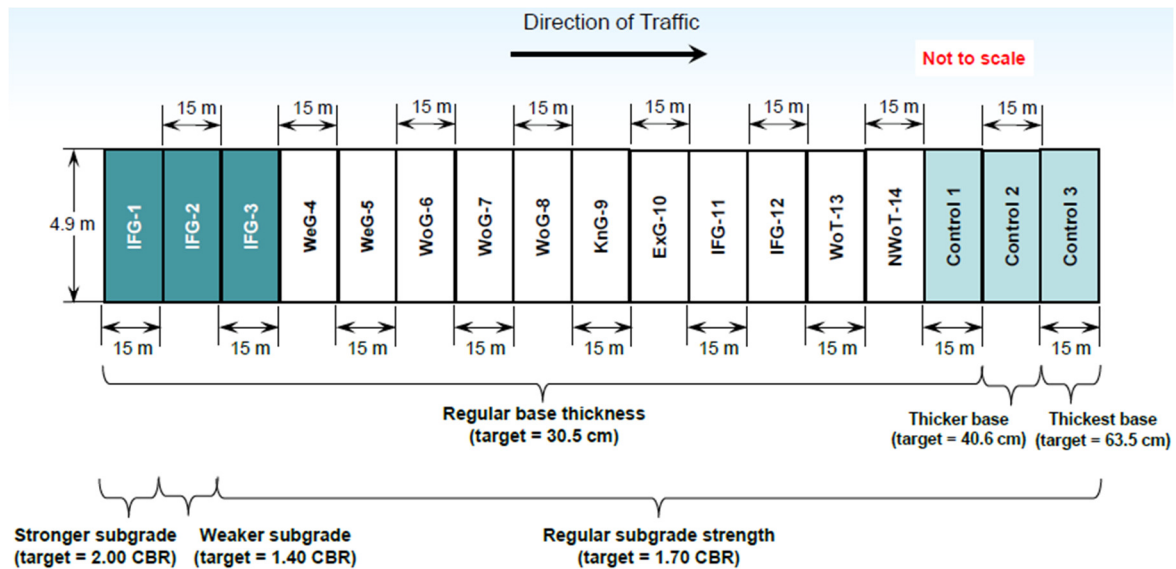
Fig. 1. General layout of test sections with target construction parameters (Source: Cuelho, Perkins 2016: 452)

However this field trial is performed using unpaved road constructions. It show which geogrid parameters has the biggest influence on their performance at a certain level of strain. German geogrid manufacturer Naue, together with Clausthal University of Technology, did a strain measurements for a paved road construction to investigate the strain level in laid geogrid reinforcement (Vollmert *et al.* 2014). This model envisaged to describe how the reinforcement effect differentiates in practice, usually in a very simplistic manner, between the interlocking effect and the membrane effect.

The instrumenting geogrid layers with strain gauges and generating data sets for in-situ conditions through additional measurements and investigations during and after construction was applied in southern ring road of the city of Altenberge in Germany. The soft soil was indicated as glacial loam and boulder clay from 0.7 to 1.8 m thick. During the geological investigations it was indicated from a stiff to semi-solid consistency, but tend to soften on water ingress and crack on drying. It had an undrained shear strength of 10 kPa. The correlated bearing strength of the soil was estimated approximately E_{v2} = 10 MPa. The soil improvement was required. To increase its ductility, the structure (e. g. see Fig. 2) was reinforced by two layers of laid polyester geogrid with 40/40 kN/m tensile strength, which has high tensile modulus and structural strength. Strain measurements were done in both along and transverse directions. Five strain gauges were installed on each geogrid layer at a spacing of 0.5 m on a geogrid bar at 90° to the road axis. This enabled measurement of vehicle passage and of the strain distribution as a function of the load spread. To capture the vertical deformations, a horizontal inclinometer covering the entire road width was positioned above the first reinforcement layer as showed in Figure 3.
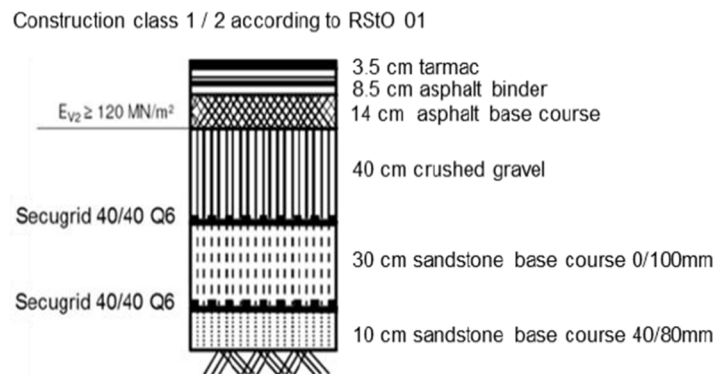
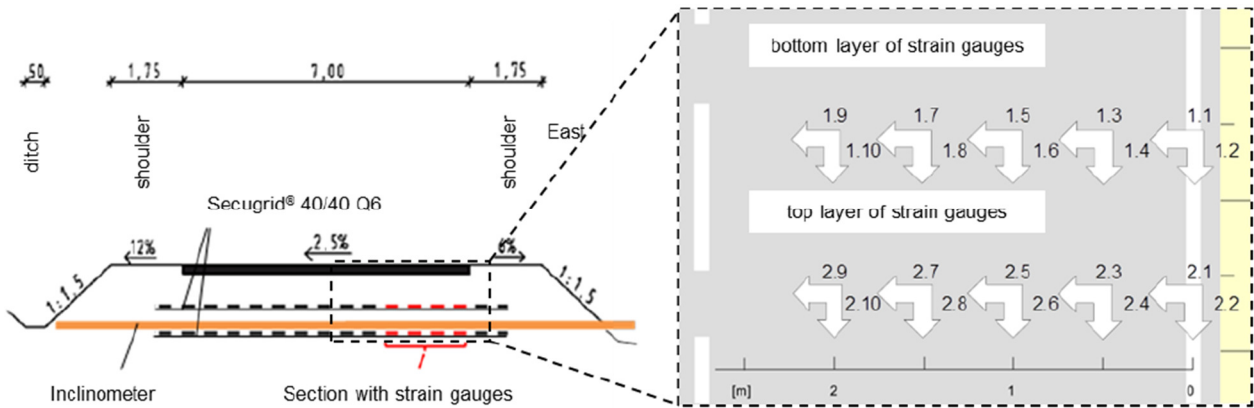Fig. 2. Road structure detail (Source: Vollmert *et al*. 2014: 157)

Fig. 3. Cross section of instrumentation, position of strain gauges and inclinometer (Source: Vollmert *et al.* 2014: 157)

The inclinometer registered approximately 10 mm settlement right after a placement the aggregate on the first layer of geogrid during the construction period. The formation of clearly visible ruts during the construction phase occur before applying the asphalt layers. The majority of deformations occur during the construction and before the crushed gravel layer is placed. The overall structure shows no further positional changes in the plane of the first reinforcement layer after the crushed gravel layers are installed. Figure 4 shows the strains transverse to the road measured at different times showed the maximum value of strain approximately at the centre of the instrumented right-hand lane and decreasing towards the edge of the lane. The base value of strain is greater in the middle of the two lanes than at the edge of the roadway. Largely uniform strains were recorded in the lower layer over the entire lane width in the trafficked direction. These are measured as largely elastic strains. The strains increase continually from the commencement of the works. Even one year after commissioning, the strains continue to increase. This is explained by the formation of ruts and the lateral movement of the entire structure due to post-construction settlement. The measurements of the strain were performed for only one year after the construction of road and the results gained shows that it needs to be monitored for more time as the strains are increasing.

When doing the plate loading test (FWD) the average bearing strength of Ev2 = 111 MPa was recorded on the crushed gravel layer at the same time the strain measured on the first geogrid layer was between 0.04 and 0.06%. The development of the measured strains over time showed significant correlation between the loading from static plate loading test and moving traffic load with simultaneous application of shear force. Although the magnitude of the maximum loading can be represented by the static plate loading test, the pronounced change between tension and compression as it is found for moving wheels cannot be represented by plate loading tests. The installed reinforcement layers clearly act to reinforce the overall structure. The strains measured here correspond well with the known results from the model road at the Montana State University field trials. Therefore selected geogrids can be considered to have a very good bond with the base course material and thus stabilize it by their strength-strain characteristics and structural stiffness. In the operating phase, the plastic strains in highly rigid structures are very small compared to the elastic ones. However, the study showed that certain amount of plastic deformation are found even in very rigid structures.
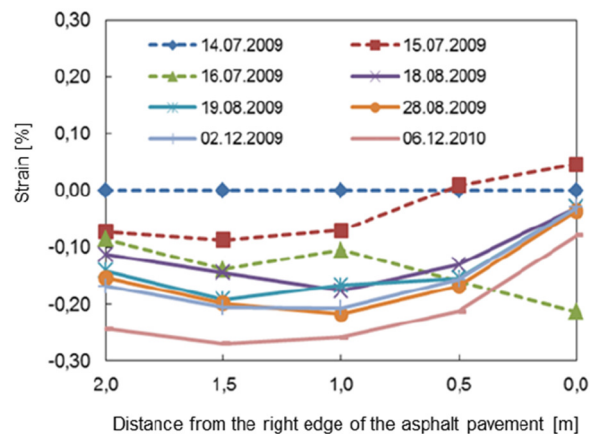

Fig. 4. Development of strains transverse to road axis over the construction period and one year of operation
(Source: Vollmert *et al.* 2014: 157)

To limit the amount of plastic deformation, tensile stresses must therefore be absorbed, even if they are developed at very small strains. The mechanogenic analogy here is rather in reinforced concrete than in the membrane theory. The stabilization of the grain skeleton at the layer boundary with the subgrade is thus necessarily linked to the uptake of tensile forces.

Lithuanian regulations and standards for geogrid reinforcement

The first set of regulations for use of geosynthetics for road embankment and subgrade reinforcement (technical specifications and methodical instructions for usage of geosinthetics *TRA GEOSINT ŽD 13* and *MN GEOSINT ŽD 13*) was released in 2013. These are the first and only regulations valid in Lithuania that describes the selection and usage of geogrids for base/subbase reinforcement. They also relates harmonised European standard *EN 13249 "Geotextiles and geotextile-related products – Characteristics required for use in the construction of roads and other trafficked areas (excluding railways and asphalt inclusion)"* (LST EN 13249:2014+A1:2015). Vaitkus, Šiukščius (2014) describes the properties and test methods of geosynthetic reinforcement products that are used for reinforcement application in technical specifications *TRA GEOSINT ŽD 13*. This description is directly related with standard *EN 13249* requirements for the reinforcement products. The required properties for reinforcing products are: mass per unit area, max. tensile strength, elongation at max. load, aperture size, durability. Methodical instructions *MN GEOSINT ŽD 13* defines geogrid as a soil reinforcement product, it shows the application areas, basic installation information, testing procedures and design example for base reinforcement. Unfortunately, there is no information about the geogrid as a subgrade reinforcement/stabilization element in the document neither an information about how it should be installed. The given theoretical propositions are based on the results gained from field trials accomplished before 2003. It shows the rut depth reliance on reinforcement element elongation on 0.2 m thick aggregate layer and defines that it is proven for reinforcing element to elongate 2% before the critical rut depth of 10 cm is reached. It is stated that reinforcing element should have 400–600 kN/m of stiffness at those elongations (Rüegger, Hufenus 2003). The only target on aggregate strength parameters are 10 cm of allowed rut depth or deformation modulus Ev2 = 45 Mpa. The crucial information is that this design example is based on unpaved road conditions.

Conclusions

To maintain a good and safe riding quality on paved roads, the designed pavement structure layers need to provide adequate stiffness to keep deformations at a tolerable low level (Vaitkus, Paliukaitė 2013). The geogrid has to have high stiffness at very low elongations, stiff junctions and rigid structure. Stiff and rigid geogrids provide a stabilization effect within the reinforcement function which efficiently reduces lateral deformations in unbound granular layers. Stabilization of unbound granular layers has to be considered as an effect which is directly linked to the reinforcement function. This needs to be clearly stated in *MN GEOSINT ŽD 13*.

Described studies have showed that under relatively thick base courses of paved roads tensile forces are activated by a reinforcement product. It showed strain levels of between 0.2% and 0.3% were generated due to stresses occurring during construction and service life of at least one year. Therefore further tests of base course bearing capacity, pavement rut depth and surface uniformity have to be carried out to fully understand the reinforced aggregate influence on paved road durability.

According to the *MN GEOSINT ŽD 13* annex 1, a minimum secant stiffness value of $S_d \geqslant 400$ kN/m at 2% strain is requested for geogrids in base course applications. If the stress-strain behaviour is considered to be linear in this particular low strain range, this value can be correlated to the strain level of 0.5% as described above.

The stiffness and tensile strength of geogrid which is designed to work during the service life of the road can only be as high as its residual strength related to the robustness against installation damage. The greater the grain size of the fill material and the higher the compaction energy, the lower is the residual strength of the geogrid. For products which are relatively sensitive to installation damage, a higher nominal tensile strength needs to be considered to compensate the reduction in strength. This property of the geogrid is not highlighted as very important parameter and it can be not evaluated in the design according the existing regulations in Lithuania.

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