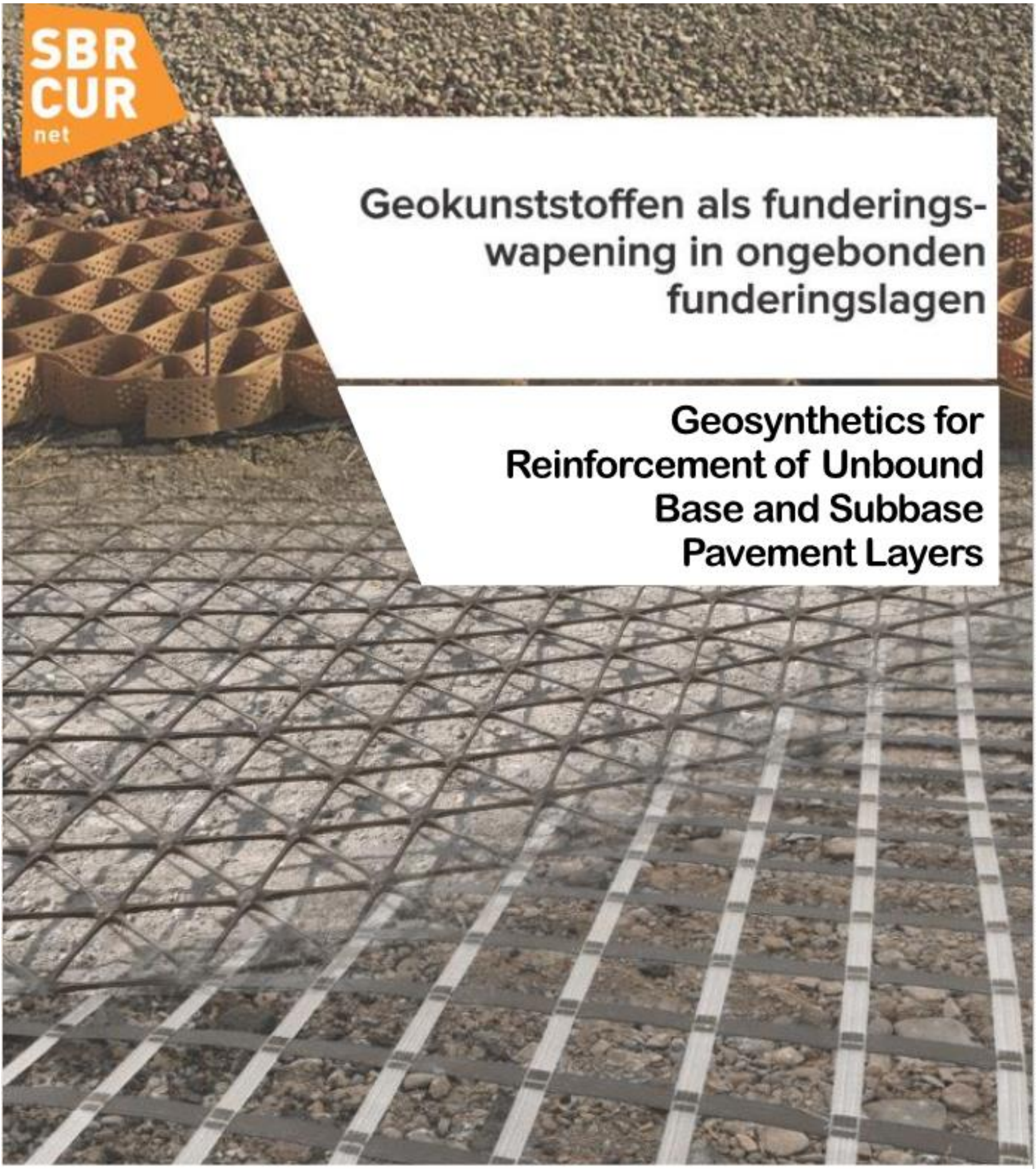

Geokunststoffen als funderingswapening in ongebonden funderingslagen

Geosynthetics for Reinforcement of Unbound Base and Subbase Pavement Layers

Guideline for Determining the Improvement Factors and Design of Reinforcement Geosynthetics in Road Building

Introduction

SBRCURnet/CROW created this Guideline to determine the added value of geosynthetic solutions to the stabilization of subgrade and reinforcement of the road base. The intent of this document is to make available design rules and current knowledge and experience available to governments and designers so that they optimize geosynthetic reinforcement for pavements. While the original guideline in Dutch discusses reinforcement geosynthetics, the following key sections on geocells were translated by PRS; all rights are reserved under copyright by SBRCURnet/CROW,

SBRCURnet/CROW, Netherlands

The Guidelines were written by a team of experts for *SBRCURnet* and distributed by CROW, two highly respected Dutch institutes that develop guidelines and standards in the fields of civil engineering, road construction and traffic engineering. The report was drawn up by SBRCURnet Committee 1991 "Geosynthetics as reinforcement in bound and unbound foundation layers". The composition of this committee was comprised of the following industry professionals cited below:

Voor de aanleg van weg-infrastructuur op de slappe bodem in het westelijke deel van Nederland is een scala aan technieken beschikbaar. De uitdaging daarbij is dat uit dat scala van mogelijkheden de economisch meest voordelige oplossing wordt gerealiseerd.
Een van de technieken die daarbij kan helpen is de toepassing van geokunststoffen als funderingswapening. In de praktijk krijgt deze techniek veelal niet de aandacht die het verdient. De reden daarvan is dat de bestaande ontwerpregels niet aansluiten op de Eurocode en de huidige stand van kennis en ervaring. Het gevolg is dat overheden en ontwerpers niet optimaal gebruik kunnen maken van de mogelijkheden die dit type fundering kan bieden.

In 1995 is CUR publicatie 175 beschikbaar gekomen onder de titel 'Geokunststoffen in de wegenbouw en als grondwapening'. Deze publicatie is opgedeeld in 2 delen. In deel 1 worden analytische ontwerpregels gegeven voor het toepassen van geokunststoffen als funderingswapening in de wegenbouw. Dit deel is sterk verouderd en sluit niet meer aan op de huidige ontwikkelingen en ontwerpmogelijkheden. De actuele stand der techniek biedt namelijk veel meer mogelijkheden om te dimensioneren en sluit daarnaast beter aan op de praktijk. Het ontbreekt echter aan een integraal actueel document waarin alle kennis en (recente) ervaring bij elkaar is gebracht. Vanuit de sector is de wens geuit om dat integrale document te ontwikkelen, opdat de toepassing van geokunststoffen als funderingswapening de impuls krijgt die de techniek verdient. Met de voorliggende publicatie, waarin de (internationale) kennis en ervaring van de afgelopen jaren is verzameld en vastgelegd, wordt aan deze wens invulling gegeven.

Het rapport is opgesteld door SBRCURnet-commissie 1991 "Geokunststoffen als wapening in gebonden en ongebonden funderingslagen". De samenstelling van deze commissie was:

Erik Rutten (voorzitter)	Provincie Zuid-Holland
Erik Kwast (rapporteur)	Kwast Consult
Hary Dekker (corresponderend lid)	Rijkswaterstaat GPO
Joris van den Berg	Bonar
Klaas Beukers	Van Oord
Aart van Bree	Provincie Utrecht
Piet van Duijnen	GeoTec Solutions
Marc Eijbersen (corresponderend lid)	CROW
Peter Galjaard	Dura Vermeer
Christ van Gurp (rapporteur)	KOAC-NPC
Hans Heurter	Waterschap Rivierenland
Theo Huybregts	Geologics
Gert Koldenhof	CITEKO
Kennard van Malenstein	Intercodam Infra
Marco Oosterveld	BAM Wegen
Jeroen Ruiter	Ten Cate
Jan Stigter	Boskalis
Joost Verschuure	Dubobol
Lars Vollmert	BBG GmbH
Jan van de Water	Dibec
Dick Wilschut	Gemeente Rotterdam
Erwin Vega (projectmanager)	SBRCURnet

Geosynthetics for Reinforcement of Unbound Base and Sub-base Pavement Layers

1.1 Introduction

Geosynthetics for Reinforcement of Unbound Base and Subbase Pavement Layers is a new Guideline Standard published in the Netherlands in 2018 published by SBRCURnet / CROW – two renowned research institutes that produce standards and regulations in the fields of civil engineering, transportation and construction. The goal of the Standard is to determine the added value of reinforcement geosynthetics in road building, based on the improvement factors and pavement design. The document collates the currently available design methods, knowledge and experience to optimize geosynthetic reinforcement for pavements, for both 2D Geogrids and 3D Geocells. The Standard is published in Dutch; the following is a brief overview in English of sections (referenced by paragraph no.) relevant to geocells (all rights reserved by the publishers).

Terminology. The following are several assumptions used in this Standard:

- **Reinforcement Geosynthetics**– the Standard focuses on mechanical stabilization by both – 2D Geogrids, which work by means of interlock between the aggregate and the grid, and – 3D Geocells, which work by confinement stress on the aggregate to improve the strength of the entire layer.
- **Reinforcement vs. stabilisation** – although there is a fine distinction between the function of base reinforcement and mechanical stabilisation, in practice, both are often used interchangeably.
- **Base Reinforcement** – in this Standard, 'base' reinforcement refers to reinforcement of the subbase and soil, as well as the base layer.
- **Selecting Reinforcement** – The Standard stresses that the selection of the reinforcement geosynthetic should be based on the design criteria; the following review discusses content relevant to Geocells.

1.2 Purpose of Base Reinforcement

As defined in the Standard: "**Base reinforcement** is the reinforcement of the bearing capacity and integrity of bases supporting roads. By applying base reinforcement, the designer, contractor or construction manager attempt to improve the structural behaviour of an unbound base, either by having to apply less material, or by achieving a longer life span in an unpaved road, or in a road paved with asphalt, concrete or paving stone. Base reinforcement may also be applied when considering working with an inferior or lightweight base material with less than optimal stability and stiffness properties." (para. 1.2.1) The relevant properties of geosynthetics for reinforcement are shown below:

Table 1. Relevant properties of geosynthetics for reinforcement function
(source: *Geosynthetics for Reinforcement* Standard)

Benefit	Dynamic stiffness modulus subgrade		
	<3OMPa	30-80MPa	>8OMPa
Limited digging for replacement of subgrade	●	◗	○
Reduced layer thickness of subbase for reduced tension on subgrade	●	◗	○
Reduced disruption of subgrade during road construction	●	◗	○
Reduced total layer build-up of road construction through subbase reinforcement	●	◗	○
Reduced total layer build-up of road construction through base reinforcement	◗	●	◗
Extension of road construction design life through reinforcement of subbase	◗ geogrid ● geocell	◗ geogrid ● geocell	◗ geogrid ● geocell
Extension of design life by reinforcing base	●	●	●

● = usually benefit; ◗ = benefit under certain circumstances; ○ = usually no benefit

The following figure shows (from left to right), a schematic application of base reinforcement in the base of an unpaved road, base reinforcement of a block pavement, reinforcement of the subbase and base of an asphalt pavement and reinforcement of only the subbase of an asphalt pavement (para. 1.2.2).

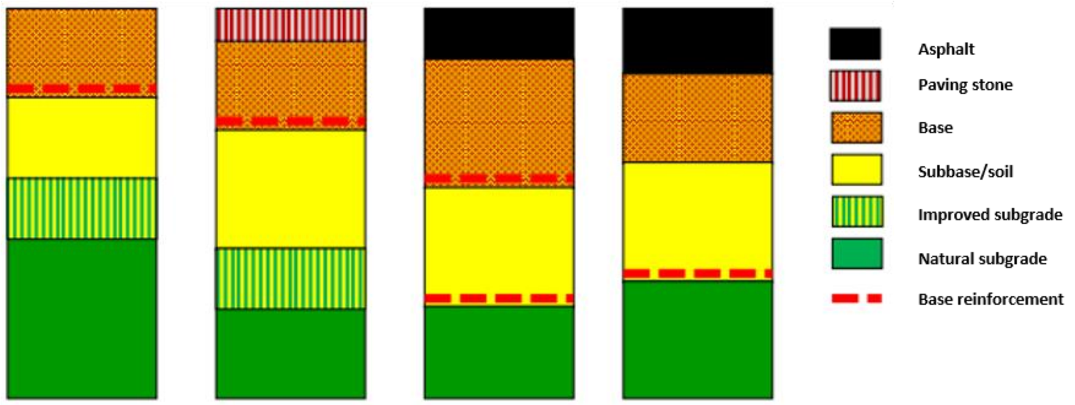

Fig. 1. Examples of base reinforcement application in base and subbase (source: *Geosynthetics for Reinforcement*)

1.3 Reinforcement vs, Stabilisation

Terminology. Although the two terms are often used interchangeably, the standard attempts to make a fine distinction between the two: "**Mechanical (stabilisation)** means that a product is applied in the unbound base material to increase the contact pressure on the surfaces between the particles of the mineral aggregate and with 3D **base reinforcement** to increase the confinement stress on the mineral aggregate to improve the overall strength of the entire layer." (para. 1.2.4)

Reinforcement is dependent upon material properties. This is one of the main points in the Standard: "(In addition to the structure of the road construction), the extent of the reinforcing or stabilising effect is determined by the material from which the product is made and the geometry. The most important material properties are the elastic stiffness and the resistance to permanent deformation (creep)…. **Materials that exhibit a lot of creep will gradually lose their reinforcing capacity over time**." (para 1.2.4).

The reinforcement mechanism is summarized as follows: "When using a geocell, Interlock occurs through the geocell walls, as well as the activation of tensile forces in the geocell, Under the vertical traffic load and the load of the overlying layers, horizontal stresses in the mineral aggregate in the geocell are generated by load distribution. This horizontal ground pressure is controlled by the cell walls, in which "hoop" tensions are generated. The "hoop" tensions and passive ground pressure in the adjacent cells prevent lateral deformation of the mineral aggregate…. As a result, shear deformation in the mineral aggregate is slowed down or prevented and the entire paving construction behaves more rigidly." (para. 1.2.4)

The limit on plastic deformation for reinforcement synthetics is defined as low deformation, e.g., **less than 2%, as elongation more than that will lead to much larger degradation of the pavement**.

1.4 Geocells

Raw Materials. "The polymers polyamide (PA) and polyethylene (PE, HDPE) are less suitable for reinforcement and stabilisation in view of the higher elongation at break and lower stiffness. Because the behaviour of small deformations is decisive for application in road bases, the PA and PE plastics will not be discussed in this publication. There are also products available that use different types of polymers to optimise their combined benefits in the end product." (para. 2.1)

Physical Description. This section describes geocells and their physical construct. Geocells are "hardly dependent on the grain size and on the mineral aggregate..." (para. 2.2.4). The effect of confinement, lateral stress and hoop stress in the cell walls is described. The geocell mechanism provides an improved spread angle through the so-called "beam effect" (see Fig. 2 below).

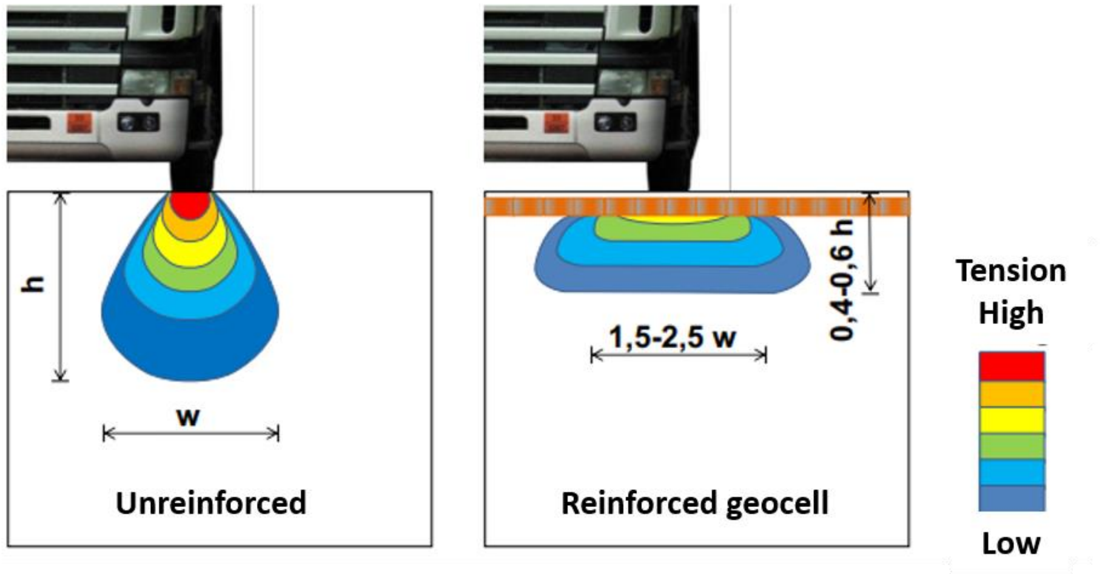

Fig 2. Improvement of load distribution by geocell in upper structural layer
(source: *Geosynthetics for Reinforcement* Standard)

1.5 Geocell Material Properties

Geocells must also have the right properties in all directions when it comes to **dynamic stiffness, resistance to plastic deformation and tensile strength** (para. 2.2.4)**.**

Table 2. Required Global Properties of Geocells for Road Base Reinforcement*
(source: *Geosynthetics for Reinforcement* Standard)

Property	**Unit**	**Testing method**	**Value**
Dynamic stiffness modulus (net) (DMA-test)	MPa	EN-ISO 6721-1 ASTM E2254	**
Cumulative plastic distortion (creep) (SIM test)	% m/m	ASTM D6992	< 3
Tensile force, non-perforated cell wall (wide width)	kN/m	EN-ISO 10319	20-29
Tensile force, perforated cell wall (wide width)	kN/m	EN-ISO 10319	16-25
Adhesion strength internal connections	kN/m	NEN-EN-ISO 13426-1 (part 1 method C)	> 17
Height cell wall	mm	-	50-200
Distance between internal connections	mm	-	330-720

* values available only for Novel Polymeric Alloy (NPA) Geocells
** values depend on application

The Standard defines the following as key properties for design with geocells and how they are verified:

Tensile strength and elasticity at maximum load. "Tensile strength is the force in kN/m that a geosynthetics produces at a certain stretch that is measured in accordance with NEN-ISO 10319. Elasticity at maximum load is the distortion of that material under maximum tensile load. Details regarding tensile force are particularly useful for the evaluation of the reinforcement function…." (para. 3.6.4)

Stiffness modulus. "The stiffness modulus of a material is a measure of its elastic deformation behaviour. The stiffness modulus is an indication of the relationship between the force exerted on a material and the associated elastic deformation. **For all types of bases, from unbound to bound, the elastic deformation behaviour is the main mechanical property.** The same applies to subbase reinforcement…. In geocells, the net dynamic stiffness modulus (DMA-test) is determined in accordance with NEN-ISO 6721-1 or ASTM E2254." (para. 3.6.5)

Creep resistance. "Creep means the non-elastic deformation, which increases with time, of a material under unchanged load. Creep in non-reinforced bound bases is described in [5]. Creep is unimportant in non-reinforced, self-binding and unbound bases. **If base reinforcement is applied, this material must be examined for its creep properties…** For geocells, the Stepped Isothermal Method (SIM) in accordance with ASTM D6992 is often used to determine the resistance to creep. (para. 3.6.10)

Tensile force of seams and joints. "Data on the tensile strength of seams and internal joints are necessary for the evaluation of the reinforcement function…. For geocells, the testing method is described in NEN-EN-ISO 13426-1 part 1, with method C1 used. Two cells connected to each other are positioned in an optimal opening condition, after which the cell connection is tested…. The test determines the tensile strength of a joint or seam between geosynthetics." (para. 3.6.6)

1.6 Design with Geocells

The design factors and methods relevant to geocell stabilization are discussed in detail in the guideline, including examples; only brief highlights are presented in the following sections.

Base Layer thickness and Reduction. "The layer thickness requirement of a base is always linked to the resistance of a construction (or component thereof) to the applied mechanical load and the dimensional stability of the construction..." (para. 3.5.11) a principle that applies to basic design as well as to reinforcement geosynthetics. Road design with base reinforcement seeks to optimize the base thickness, with the quantity of materials and material properties.

Design Methods: Design Aspects by Mechanical Stress. An inventory study of 17 design methods was carried out and analysed. The pluses and minuses of each method for each type of design method were evaluated. The following checklist was used (para. 4.2.1):

- Background;
- Model validated to practice measurements, laboratory measurements or otherwise;
- Input parameters;
- Calculation results; output of the method;
- Applicability
- Type of design method (numerical, empirical or analytical);
- Possibility of input of axle load repetitions

Unpaved Roads. Resistance to permanent deformation is the most important design criterion. Empirical models are used to determine the base thickness to limit rutting. Both the Giroud-Noiray and the Giroud-Han models are recommended for the design of base reinforcement of unpaved roads and paving blocks. These models utilize correction factors to express the performance in unpaved roads of specific geocell product, based on experimental studies (para. 4.5.1). The Standard includes a detailed discussion of how to use these models (para. 4.5).

Asphalt Pavements. "In the design calculation of asphalt pavements, a stiffness modulus is assigned to each construction layer. This load capacity indicator is in many cases not constant but depends on the stiffness of the underlying layers and the layer thickness. **The contribution of base reinforcement is therefore expressed in an increased stiffness modulus.**" (para. 4.1) "In this publication, the AASHTO model was (chosen), with some adjustments that take into the account the reinforcement product, the bearing capacity of the substrate or substructure and the stiffness of the layer in which the product is applied." (para 4.2.2). The Standard includes a detailed discussion of how to use these models (para. 4.7)

Additional Design Factors. The discussion describes the factors to be taken into account, which are beyond the scope of this review: traffic load, importance of construction phase ("The quality of the base is highly dependent on the degree of compaction"), subgrade stiffness, base aggregate stiffness, and substructure stiffness.

Substructure Stiffness. For the subbase, the stiffness modulus is increased by the application of geocells. The improved confinement increases the stiffness of the subbase over the height of which the geocell is effective. **The degree of stiffness increase will depend on the validated Support Improvement Factor (SIF) and MIF (Modulus Improvement Factor) values indicated by the relevant supplier (see description below)**

Support Improvement Factor. The reinforcing effect of base reinforcement depends on: (para. 4.4.3)

- the characteristics of the geosynthetics
- the mineral aggregate in which the product is used
- location in the structural pavement

Limits to the stiffness of a granular layer depend on the thickness and stiffness of the layer under the granular layer. With the Shell pavement design method for asphalt roads, the stiffness of an unbound granular layer is at most 4x as large as that of the underlying layer. "The same principle also applies to granular layers with base reinforcement. The relative stiffness increase will be greater than when using an unreinforced granular layer because of the beam effect (see Fig. 3) … The maximum improvement factor of the reinforced layer in relation to the underlying layer is indicated by the Support Improvement Factor." (para. 4.7.2)

For example, "if for a reinforcement product in the subbase, the support improvement factor SIF = 5, this means that the stiffness of the subbase over the effective height of the reinforcement product is up to 5x the stiffness of the underlying medium. If the base has a stiffness of 30 MPa and the reinforcement is directly on the subgrade, then the stiffness of the reinforced part of the subbase on the basis of the SIF is maximum 150 MPa. For most reinforcement products, the value of SIF is independent of the stiffness of the underlying medium." (para. 4.7.2)

Modulus Improvement Factor. For a geocell with a MIF = 3, this means that the stiffness of the subbase over the effective height of the geocell is 3x the stiffness of the mineral aggregate in the unreinforced situation. "The stiffness of mineral aggregate in an unreinforced subbase depends on the bearing capacity of the subgrade and the layer thickness of the subbase. With increasing values of bearing capacity of underlying medium and increasing layer thickness of the subbase, the stiffness of a subbase in an unreinforced situation increases. Fig. 3 clarifies this relationship." (para. 4.7.2)

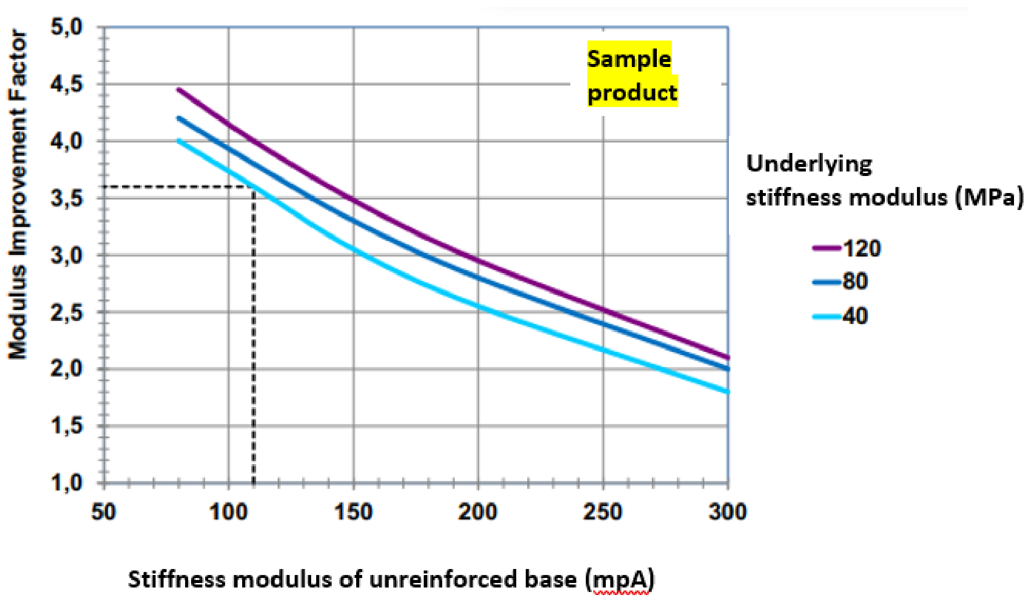

Fig. 3. Relationship of MIF and stiffness of substructure and base
(source: *Geosynthetics for Reinforcement* Standard)

Zone of Confinement. "Geocells with rigid walls have a reinforcing effect over the entire height of the geocell…. the height of the geocell (is) the effective height plus two cm of mineral aggregate above the geocell. Above that, the reinforcing effect slowly decreases and at a distance of six to eight times the maximum grain diameter from the top geocell, it will no longer be detectable or present. If this type of geocells is placed somewhere halfway in the (sub)base, the direct reinforcing effect is also visible and can be added to the two cm under the cells. In geocells with flexible walls, the full reinforcing effect usually extends over the total height of the geocell minus the upper cm." (para 4.7.2)

1.7 Design Example - Mechanical Stabilisation of Subbase

The subbase or base or both can be mechanically stabilised by applying base reinforcement. The stiffness modulus of a subbase or base is increased by the application of geocells.... The design procedure is similar for both. The extent to which reinforcement in the subbase can increase the stiffness modulus of that layer depends on the working height of the reinforcement and the factors SIF and MIF.

The definition of the reinforcing effect of the subbase is explained by the example in Fig. 4 (para. 4.7.3).

- The product is applied to the subgrade, i.e. in the lowest part of the subbase.
- The effective working height of the geocell is 200 mm.
- The manufacturer of a rigid geocell sets the SIF = 5 and MIF = 3.
- The dynamic stiffness of subgrade is 40 MPa.
- The stiffness modulus of the sand can be up to 200 MPa.
- Compacted sand of 750 mm (C1) and 500 mm (C1) for control sections.

NOTE*: The values for SIF and MIF given in the example serve solely to clarify the design procedure. In practice, products are available with both higher and lower values for SIF and MIF.*

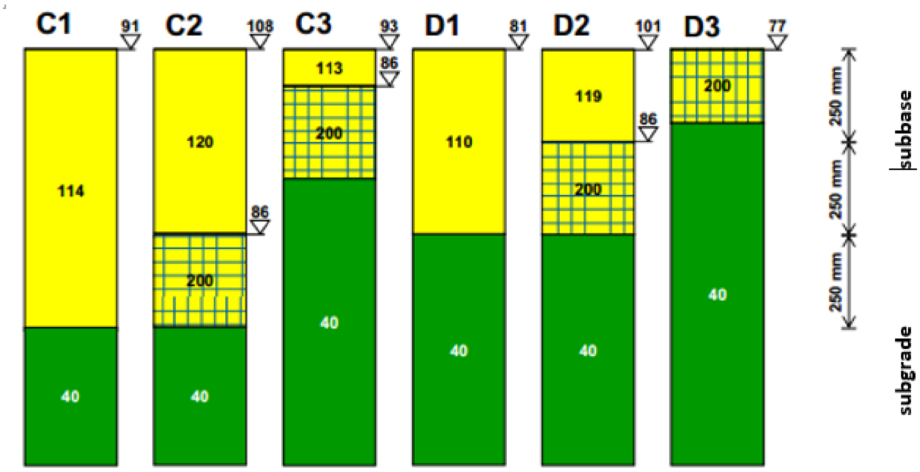

Fig. 4. Example of subbase stabilisation
(source: *Geosynthetics for Reinforcement* Standard)

NOTE*: The numbers indicate the dynamic stiffness moduli of the sublayers, subbase and the subgrade in MPa. The value in the triangle is the equivalent stiffness modulus of the entire substructure.*

Discussion. The equivalent stiffness (measure for bearing capacity of substructure) for the both subbase thicknesses (C2, D2) increases by 20% with geocell reinforcement. However, sections C3 and D3 show that layer thickness of the subbase can be halved with equal total load bearing capacity. In practice, it is of course possible to opt for an interim solution between improving the bearing capacity and reducing the layer thickness of the subbase. Once the stiffness moduli are per layer, these can be used in pavement design software as input variables to further complete the design of reinforced asphalt pavement. (para. 4.7.3)

Note*: this applies to the example presented. In practice, far better performance may be achieved by optimally showing the performance of the base reinforcement in the design.*

Additional examples are given in the Standard for both geocells and geogrids showing the impact of reinforcement in different locations in the pavement structure. The optimal location of the (sub) base reinforcement depends strongly on local conditions and if the design objectives are to reinforce soft subgrade, increase base layer stiffness and/or reduce layer thickness. The design calculation of mechanical stabilisation in the base is done the same way as for the subbase.

1.8 Summary

This section presented translated highlights of the new ‘groundbreaking’ Geosynthetics for Reinforcement Dutch Standard for reinforcement geosynthetics. The Standard consolidates the current knowledge about Geocell design principles, properties and mechanisms of reinforcement to bring a more unified understanding of the use of Geocell technology in roadway reinforcement. The Standard emphasizes that while key factors in geocell performance – elastic stiffness and resistance to deformation – are dependent upon the geocell material properties.