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ADVANCED DESIGN METHODOLIGY FOR THE PREDICTION OF THE EV2 DEFORMATION MODULUS INCLUDING STABILIZING GEOGRID

Abstract

Depending on the selected (sub)base material, either geogrid stabilized or granular fill only, the online design tool Tensar+ considers a Ev2 deformation modulus starting point on the natural subsoil, using the surface integral of various incremental performance characteristics curves to determine the fill layer thickness to achieve an Ev2 target value on top of the respective (sub)base layers. This derived Ev2 target value is in turn the starting point for the next Ev2 input value for the overlying section. In this way, the "advanced Ev2 method" is able to approximate every achievable Ev2 target value for all (sub)base layers and thicknesses. This paper describes the derivation of an Ev2 based design methodology, facilitating a multi-layered subbase and base structure considering a variety of unbound materials and the inclusion of stabilizing multiaxial geogrid. The objective of the design methodology is the approximation of the achievable deformation modulus Ev2 on top of a defined set of (sub)base layers. This method exclusively addresses the prediction of an Ev2 value as defined in DIN 18134 derived by performing a plate load test using a 300 mm diameter plate. An analysis of existing documentation and field trials has resulted in the derivation of the defined "advanced Ev2 method" model. The basis for the derivation of the required prediction of the (sub)base behaviour referred to as “performance characteristics”, result from an detailed analysis of specialist sources. Other sources include 30 years of Tensar know-how and international experience in dealing with loading plate pressure tests and Ev2 design predictions. An extensive set of validations, both legislative and in the form of a large set of field trials shows excellent agreement with the described model.

Keywords

Ev2 deformation modulus, multiaxial geogrids, stabilization, design methodology, validation, ground improvement, base, subbase

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1. INTRODUCTION

This paper sets out the derivation of an E_{v2} based design methodology, facilitating a multi-layered subbase and base structure considering a variety of unbound materials and the inclusion of stabilizing multiaxial geogrid. The objective of the methodology is to predict the achievable E_{v2} deformation modulus on top of a defined set of (sub)base layers. This method exclusively addresses the prediction of an E_{v2} value as defined in [1] derived by performing a plate load test using a 300 mm diameter plate.

A empirical analysis of various sources has resulted in the derivation of the defined model. The basis for the derivation of the required prediction of the (sub)base behaviours, below referred to as performance characteristics, result from an detailed analysis of specialist sources like [2], [3] and [4]. Other sources include 30 years of Tensar know-how and international experience in dealing with loading plate pressure tests and E_{v2} design predictions.

2. DEFINED MODEL AND ANALYSIS

A specific "performance characteristic" is assigned to each (sub)base layer or geogrid stabilized (sub)base layer. This "performance characteristic" essentially depends on three important influencing factors:

- Mechanical properties of the (sub)base material (here: material stiffness)
- Layer thickness of (sub)base material
- Stiffness of the natural subsoil

All performance characteristics are formulated incrementally and can be described using one equation f(x) with x = E_{v2} (MPa) and y = (mm/MPa). In this way, the underlying fundamental question has been answered: "How many millimetres of layer thickness of a specific (sub)base material is required to achieve an specified increase in E_{v2} (MPa)"

An incremental approach over the whole E_{v2} influence area subsequently allows for discrete division on the level of individual (sub)base layers, taking into account a variety in (sub)base materials and possible inclusion of geogrids. Using the surface integral of the E_{v2}-equation f(x), the required layer thickness can be determined for each used (sub)base material and associated E_{v2} starting value (a) and required E_{v2} target value (b) (see Figure 1).

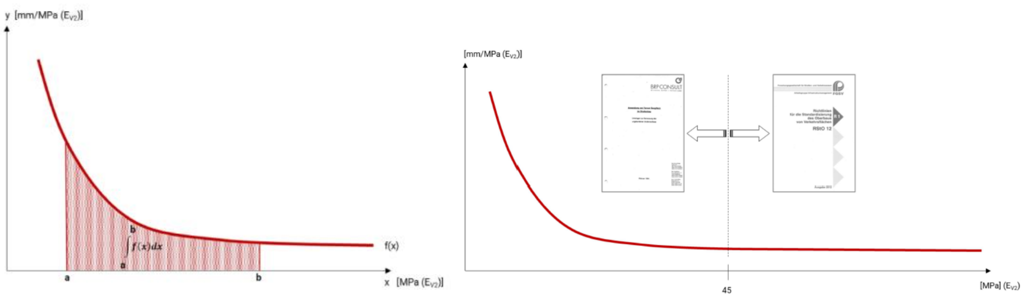

Figure 1. [left] Indicative depiction of an incremental performance characteristic f(x) & [right] Visualization of the source for the respective incremental performance characteristic

Thus, every unbound (sub)base material will theoretically be able to achieve the required E_{v2} value on top of the associated layer in relation to its specific layer thickness, material property, presence of geogrid, and the subsoil stiffness.

In the course of the development of the "advanced" E_{v2} design method, the following key aspects have been detailed:

- Definition of the material properties of the (sub)base materials (without geogrid)
- Definition of the material properties of the (sub)base materials (with geogrid)
- Definition of the zone of influence of the stabilizing multiaxial geogrid
- Validation of design methodology

2.1. DEFINITION OF THE MATERIAL PROPERTIES OF THE (SUB)BASE MATERIALS (WITHOUT GEOGRID)

The incremental material properties of the (sub)base material must be defined for the full usable E_{v2} spectrum. In order to derive realistic and verifiable values, the insights from [2] and [4] have been utilized. For this intended purpose, both sources can be used in unison as each covers a different range of the E_{v2} starting values. (Figure 1). [2] is utilized to define the performance criteria for E_{v2} starting values ≥45 MPa. The basis of the derivation can be found in table 8 from [2]. The performance characteristics for E_{v2} starting values <45 MPa are derived from the [4] report. The basis of this derivation can be found in appendices 6.2.1 and 6.3.1 from [4].

The uniform equation that describes the performance characteristics over the full range of E_{v2} starting values 45≥MPa<45 (Figure 1), is grafted together from three distinct types of equations.

- A 3rd degree polynomial is utilized to mathematically describe the behaviour in the lowest bearing capacity ranges.
- Medium bearing capacity areas are mathematically represented by a power equation.
- The high bearing capacity range is mathematically described with a linear equation.

Engineering judgement is utilized to approximate a smooth and meaningful transition between the three curve types into one fluent line as represented in (Figure 1). This approach has shown to be most accurate and reliable to mathematically describe the performance behaviour of the (sub)base materials.

The range of analysed (sub)base materials is in both [2] and [4] covered in full, where both refer to the requirements as given in the [5]. The following analysed (sub)base materials are thus defined:

- crushed rock base layer (STS)
- rounded gravel base layer (KTS)
- frost protection layer, mostly broken (FSS,b)
- frost protection layer, mostly round gravel (FSS,r)
- frost protection layer, sand (Sand)

Analog to table 8 [2], each of these (sub)base materials has a maximum achievable E_{v2} value assigned (E_{v2} limit value). This limitation ensures that the mathematically predicted E_{v2} target values are not overestimated and achievable on the construction site. To further ensure the reliability of the model predictions, all defined (sub)base materials have a range of allowable grading ranges, surface structure and stiffness as described in Figure 2. The E_{v2} prediction model should be exclusively used with assurances of application of these (or near these) defines (sub)base materials.

Mindestanforderungen				
Schüttmaterial		Eigenschaften		
Bezeichung	Beschreibung (E_{V2}-Grenzwert)	Sieblinienbereiche (Körnung) gemäß ZTV SoB-StB	Oberflächenstruktur gemäß TL Gestein-Stb (DIN EN 933-5)	Steifigkeit in Anlehnung an RDO Asphalt
STS	Schottertragschicht (180 MPa)	0/32 - 0/45 - 0/56	$C_{100/0}$	325 MPa
KTS	Kiestragschicht (150 MPa)	0/32 - 0/45 - 0/56	$C_{NR/70}$	200 MPa
FSS, b	Frostschutzschicht, überwiegend gebrochen (120 MPa)	0/32 - 0/45 - 0/56 - 0/63	$C_{50/30}$	175 MPa
FSS, r	Frostschutzschicht, überwiegend rundkorn (120 MPa)	0/32 - 0/45 - 0/56 - 0/63	$C_{NR/70}$	125 MPa
Sand	Frostschutzsand (60 MPa)	0/8 - 0/11	C_{NR}	75 MPa

Figure 2. (sub)base material properties used in the "advanced E_{v2} design"

The qualitative line graph of the incremental performance characteristics of each (sub)base material can be seen in Figure 3. The performance curves clearly show that (sub)base materials with a broken surface structure (STS and FFS,b) require significantly thinner layers compared to (sub)base materials with a predominantly rounded surface structure (KTS, FFS,r and sand) to achieve any E_{v2} target value. These broken surface structure (sub)base materials have been assigned lower increments (mm/MPa), and thus result in a thinner layer thicknesses under otherwise equal conditions compared to rounded surface structure materials.

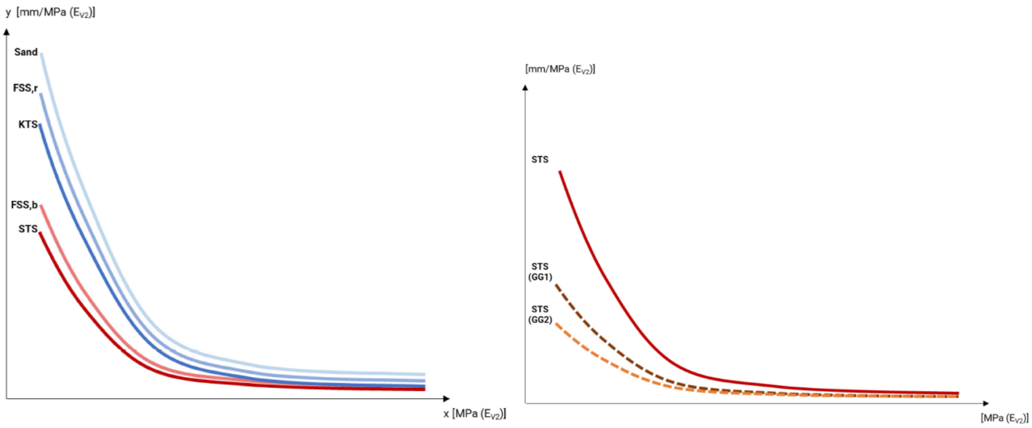

Figure 3. Qualitative depiction of the incremental performance characteristics of all defined fill materials (without geogrid left) STS without and stabilized with different geogrids right ($GG_{1/2}$)

2.2. DEFINITION OF THE MATERIAL PROPERTIES OF THE (SUB)BASE MATERIALS (WITH GEOGRID)

Extensive investigations [8, 9] have shown that the mechanical load-bearing and deformation behaviour of (sub)base materials is significantly improved when stabilized using multiaxial geogrids. Normative in achieving these benefits is the function "stabilization" as defined in (ISO 10318-1): "Improvement of the mechanical behaviour of an unbound granular material by including one or more geosynthetic layers such that deformation under applied loads is reduced by minimizing movements of the unbound granular material"

While stabilizing, the multiaxial geogrid ensures the improvement of mechanical behaviour essentially through the confinement and interlock of granular particles in the geogrid openings (Figure. 4). This results in a significantly higher load-bearing capacity and deformation behaviour of the mechanically stabilized (sub)base materials.

In relation to these mechanisms, an adequate compaction becomes essential to the performance behaviour of the (sub)base materials. A higher compaction rate of the (sub)base materials will result in a more efficient improvement of the mentioned higher load-bearing capacity and deformation behaviour. This increase in efficiency is however dependent on the given conditions. For example, granular layers cannot be sufficiently compacted over subgrade soils with low bearing capacity [7]. An inadequate compaction of the (sub)base material in turn leads to an negative influence on the mechanical behaviour of these (sub)base layers, resulting in suboptimal stiffness levels of these layers. With low bearing capacity subsoils, stabilizing multiaxial geogrid significantly improve the compaction efficiency, resulting in stiffness levels where the (sub)base layers can optimally benefit from [9].

Figure 4. Interlock of granular fill in the geogrid apertures (Tensar InterAx geogrid)

The compaction efficiency can, among other things, be derived via the execution of a plate load test as defined in [2] (using a plate diameter of 30 cm). The measured deformation modulus E_{v2} gives a measure of the compaction efficiency and allows for back-calculation of the stiffness behaviour of the (sub)base materials. When deriving the incremental performance characteristics of the geogrid-stabilized (sub)base materials, the following aspects are taken into account:

- Geogrid type
- Interaction behaviour

2.2.1. Geogrid type

The structural influence of the stabilizing multiaxial geogrid has a significant influence on the compaction efficiency. Next to the manufacturing method, aspects like node & rib form, opening geometry, mass and base material composition are all factors that matter. In their entirety, these aspects lead to a specific performance characteristics per specific geogrid which the analysis in this paper has taken into account. In relation to the stiffness of the subsoil, different geogrid types will have varying effectiveness.

Takin the incremental performance characteristics as an example, a crushed rock base layer (STS) including the effect of two distinct stabilizing multiaxial geogrid with varying structural characteristics ($GG_{1/2}$) are qualitatively shown. Inspecting Figure. 3 it becomes evident that geogrid GG_2 (here: co-extruded geogrid) opposite to GG_1 (here: mono-extruded geogrid) has a higher effectiveness when applied on low bearing subsoils, recognizable as the shallower incremental performance characteristics curve. Shallower increments (mm/MPa) in turn lead to thinner layer thicknesses with the same E_{v2} target values. On the other side it becomes clear when the subsoil is stiffer, the incremental performance characteristics of the Geogrids ($GG_{1/2}$) approach each other and even fully overlap at some point. In view of the optimization of the compaction efficiency (E_{v2}) it is clear that the benefit of GG_2 becomes negligible compared to GG1 at these higher subsoil stiffnesses. Furthermore, it is worth noting that at higher subsoil stiffnesses the incremental performance characteristics from both Geogrids ($GG_{1/2}$) approach the performance characteristics of the crushed rock base layer (STS) itself and even overlap. In view of the optimization of the compaction efficiency (E_{v2}) it is clear that the benefit of any GG becomes negligible.

2.2.2. Interaction behavior

The interaction behaviour between geogrid and (sub)base material has an influence on the incremental performance characteristics of the geogrid stabilized (sub)base material. In the described design methodology the interaction influence is considered in relation to the grading range (grain size) or surface structure (grain shape) of the (sub)base materials and the geometrical expression of the geogrids. Figure. 5 shows the interaction behaviour in relation to the (sub)base material grain texture.

Within the performance characteristics of geogrid stabilized (sub)base materials the reduced interaction behaviour of the increase in increments is taken into account.

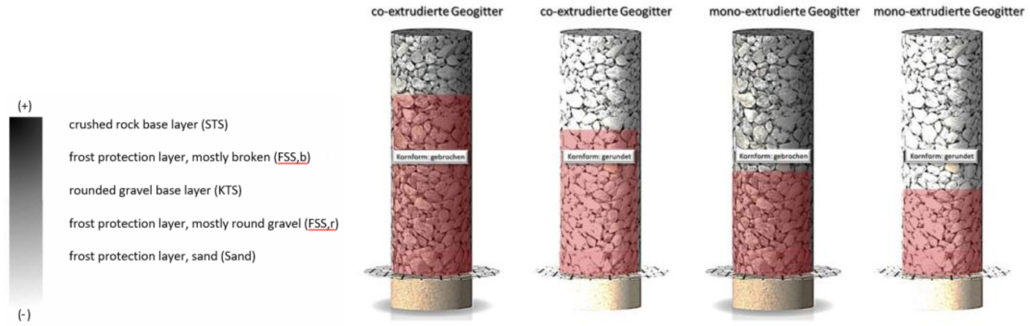

Figure 5. Qualitative depiction of interaction behaviour in relation to the (sub)base material & geogrid & Increased vertical sphere of influence in relation to Geogrid type and grain shape

2.3. DEFINITION OF THE ZONE OF INFLUENCE OF THE STABILIZING MULTIAXIAL GEOGRID

A essential aspect within the design methodology is the limitation of the vertical geogrid influence area. The incremental performance characteristic of the geogrid stabilized (sub)base materials is only sensible if realistic limits are defined. Analogeous to interaction behaviour, this zone of influence is dependent on the grading range (grain size) or surface structure (grain shape) of the (sub)base materials and the geometrical expression of the geogrids. Within one geogrid category, the vertical area of influence is larger for fill materials with a broken grain shape than for fill materials with a rounded grain shape. The zone of influence of co-extruded multiaxial geogrids is spatially more pronounced as for mono-extruded multiaxial geogrids (Figure. 5).

2.4. VALIDATION OF DESIGN METHODOLOGY

2.4.1. (sub)base materials without geogrids

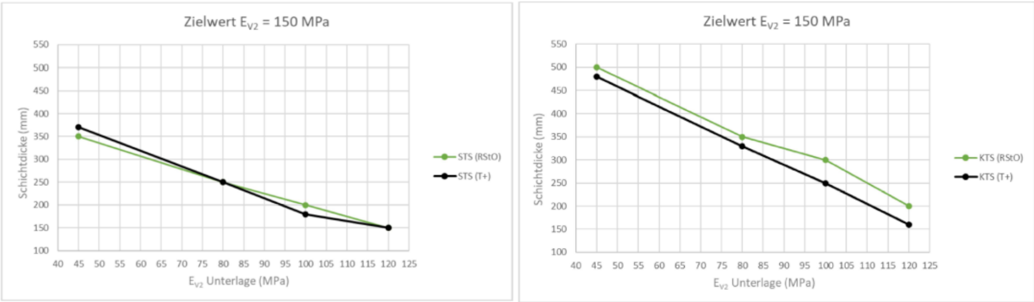

Figure 6. Validation for crushed rock base layer (STS) & rounded gravel base layer (KTS) [2]

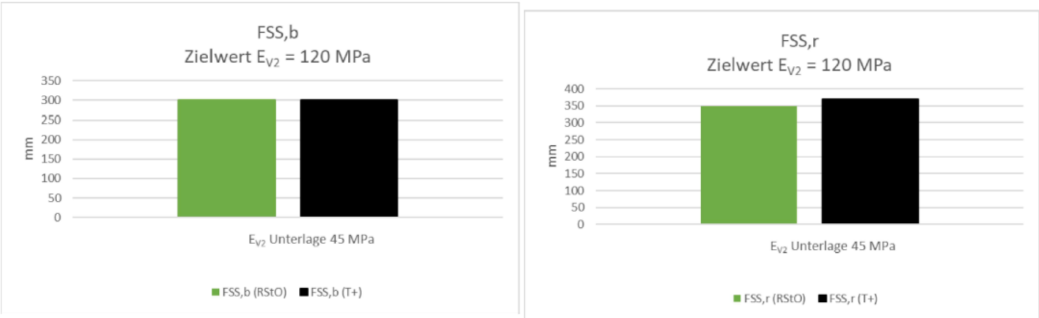

Figure 7. Validation for frost protection layer, mostly broken (FSS,b) & mostly round gravel (FSS,r) [2]

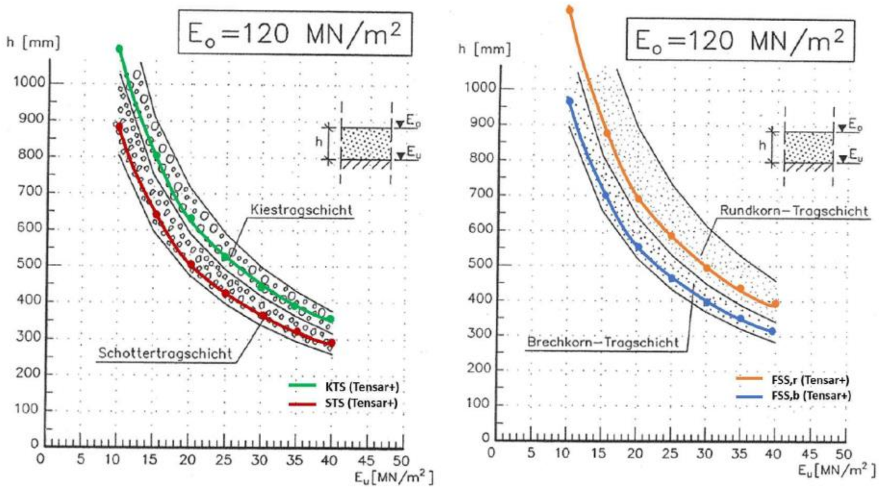

Figure 8. Validation results of rounded gravel base layer (KTS) and crushed rock base layer (STS) & frost protection layer, mostly broken (FSS,b) round gravel (FSS,r) [4]

2.4.1. (sub)base materials with geogrids

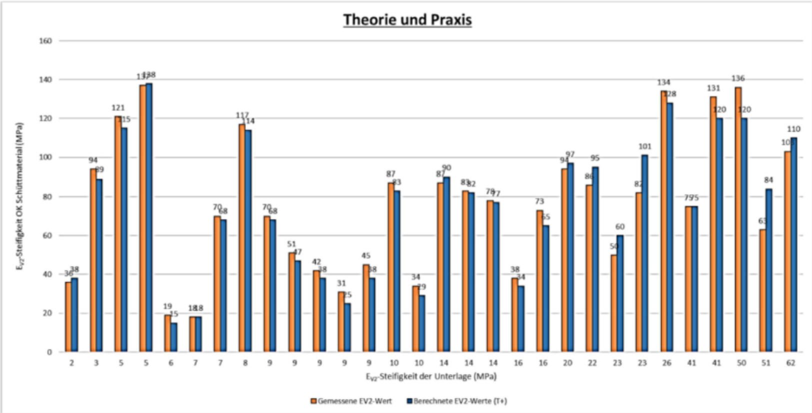

Figure 9. Comparison between measured and calculated (including multiaxial geogrid)

A statistical evaluation of the utilization percentage "Theorie vs Praxis" indicates that the incremental performance characteristics of (sub)base materials with stabilizing geogrid overall tends to be light conservative at a mean = 98%. Furthermore, a standard deviation of 8% is a relatively low degree of uncertainty for such a varied dataset.

3. CONCLUSION

The "incremental performance characteristics" for all (sub)base materials included stabilizing geogrids show very good to excellent agreement with a large and varied set of literature sources and field verification trials measured E_{v2} values. All incremental performance characteristics can be viewed as sufficiently and accurately validated.

LITERATURE

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