SMARTRAIL WP3

User Guidelines

IMPLEMENTATION OF GEOSYNTHETICS FOR REHABILITATION OF OLD BALLASTED RAILWAY TRACKS

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1. Introduction

These guidelines provide a description of the work necessary in order to deliver the benefits as described in the SMARTRAIL Work Package No. 3 (WP3). The project website www.fehrl.smartrail.org contains full details of all the results from the individual Work Packages in addition to further information concerning the project.

2. Geosynthetics in rail tracks

It is a worldwide trend nowadays to increase axle loads, traffic density and speed to reduce operating costs and increase the efficiency of railways. These new operational conditions define the new requirements for infrastructure, regarding its deformation behaviour and fatigue processes. Thus, not only new construction elements to the track superstructure are required, but also a rehabilitation of the old railway track substructure including improvements of the railway subgrade bearing capacity is required.

Satisfactory performance of ballasted railway track depends primarily on the repeated loading response of the granular material, particularly material in the ballast layer and gravel material in the sub-ballast layer. Also affecting the performance of the granular layer is the subgrade material and its compressibility. According to Indraratna (2011), the reduction of ballast degradation is imperative in order to sustain the primary functions and overall performance of the superstructure. This can be achieved by preventing ballast contamination, i.e. the pumping of fines from subgrade and the degradation of ballast grains, thus also maintaining the draining properties of the ballast layer.

2.1 Functions of geosynthetics within railway construction

Geosynthetics are used for various purposes with regard to rail tracks, most commonly with the aim of increasing the bearing capacity of the subgrade soil, to prevent contamination of the ballast by subgrade fines and also to dissipate the high pore water pressures built up by cyclic loading.

Harmonized European Standard EN 13250:2001 defines three primary functions of geosynthetic products to be used in the construction of railways:

- Filtration
- Separation
- Reinforcement

Besides these three functions, the additional purposes of geosynthetics within railway construction can also include:

- Drainage.

These four functions are mainly incorporated into six types of geosynthetics. These are listed in Table 1.

Table 1. Identification of usual primary function versus type of geosynthetic (modified from Koerner, 2012)

Type of geosynthetics	Primary function			
	Separation	Reinforcement	Filtration	Drainage
Geotextile	x	x	x	x
Geogrid		x		
Geonet			x	
Geocell		x		
Geofoam	x			
Geocomposite	x	x	x	x

2.2 Polymeric materials

The vast majority of geosynthetics are made from synthetic polymers, also known as plastics. Besides these, particularly for the production of reinforcing geocomposites, glass and carbon fibres and steel are used. Synthetic polymer consists of many repeating structural parts called monomers, which are bonded together in a chain. The type and length of the chain primarily defines the characteristics of polymer. Various additives such as UV stabilizers, antioxidants, thermal stabilizers etc., might be added to polymer fibers to achieve specific properties of a geosynthetic.

Among the polymer fibres, polyethylene and polypropylene are the most common in the production of geosynthetics, particularly in geosynthetics that are used within railway construction. Some of their physical properties are set out in Table 2.

Table 2: Some physical properties of most common polymer fibres used in geosynthetics within railway construction

Fiber	Specific gravity	Coeffiecient of thermal expansion (x10^{-5}/°C)	Melting temperature (°C)
Polyethylene (HDPE)	0.94-0.96	13	110-140
Polypropylene (PP)	0.85-0.95	6	160-170

2.3 Relevant characteristics of geosynthetics within railway construction

European Standard EN 13250:2001 specifies the relevant characteristics of geosynthetics to be used in the construction of railways, and the appropriate test methods required to determine these characteristics.
EU Regulation No. 305/2011 on conditions for the marketing of construction products introduces a Declaration of performance for construction materials. A Geosynthetic manufacturer is required to prepare such declaration for every single product intended to be

used within railway construction. This document must declare values for characteristics relevant to their intended use within railways. Depending on the expected function of geosynthetic within rail track, essential characteristics are presented in Table 3. Test methods for the evaluation of these characteristics are also listed.

Table 3: Function-related essential characteristics of geosynthetics used in the construction of railways and test methods to be used (based on EN 13250:2001)

Characteristic	Test method	Functions		
		Filtration	Separation	Reinforcement
Tensile strength	EN ISO 10319	x	x	x
Elongation at maximum load	EN ISO 10319			x
Static puncture (CBR test)	EN ISO 12236		x	x
Dynamic perforation resistance (cone drop test)	EN ISO 13433	x		x
Characteristic opening size	EN ISO 12956	x		
Water permeability normal to the plane	EN ISO 11058	x		
Durability (weathering)	EN 12224	x	x	x

Manufacturers of a specific geosynthetic declare the values of essential characteristics of the material in the declaration of performance by providing its mean value and standard deviation.

3. Recommended values of essential characteristics

Amongst all the listed functions of geosynthetics within railway construction, drainage is less essential (and thus also not mentioned in Table 3). This is due to the coarse materials used in upper layers (ballast bed and formation layer), which should enable good drainage by themselves. Thus filtration and separation should be assured to prevent clogging of coarse material.
The design of geosynthetics in railroad applications should include design of separation, filtration and reinforcement (Koerner, 2012). It can be placed beneath ballast as well as beneath the formation layer where formation layers are being used. This happens particularly in cases of soft subgrade/subbase material with a low bearing capacity. While separation and filtration characteristics of geosynthetics do not noticeably depend on location (beneath the ballast or beneath the formation layer), required mechanical characteristics may be dependent on its location and are therefore taken into account in the following recommendations.

Two important issues to consider in the design of geosynthetics in railway tracks are:

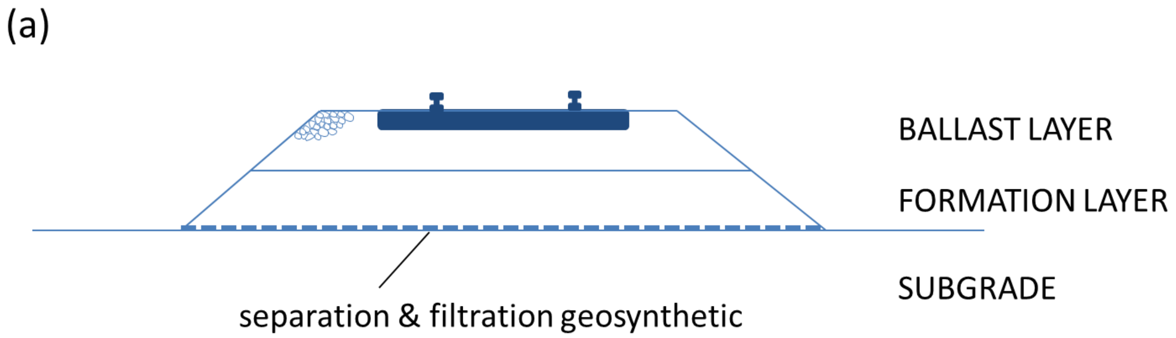
a) The depth of the geosynthetic beneath the bottom of the sleeper.
The very high dynamic loads are acting on the ballast stones and are gradually diminishing with depth. Geosynthetics, if not located deep enough, can suffer from abrasion due to dynamic loading through contact with ballast. However, geosynthetics might also be damaged by ballast tamping procedures during railtrack

maintenance works. Thus, it is recommended to place geosynthetics only deeper than 35 cm beneath the sleeper in order to prevent damage from the two reasons mentioned above.

b) The survivability of the geosynthetic during installation.
Due to the compaction works performed on the formation layer and due to the tamping of ballast under the sleepers, it is essential to use only geosynthetics with a high puncture resistance.

2.4 Separation and filtration geosynthetic

To prevent the pumping of fines from the subgrade into the formation layer due to the dynamic loading of railway traffic, separation and filtration geosynthetics are used. They are required to prevent the passing of fines to upper layers whilst at the same time they must allow pore water from the subgrade to easily filtrate in the direction to the surface.



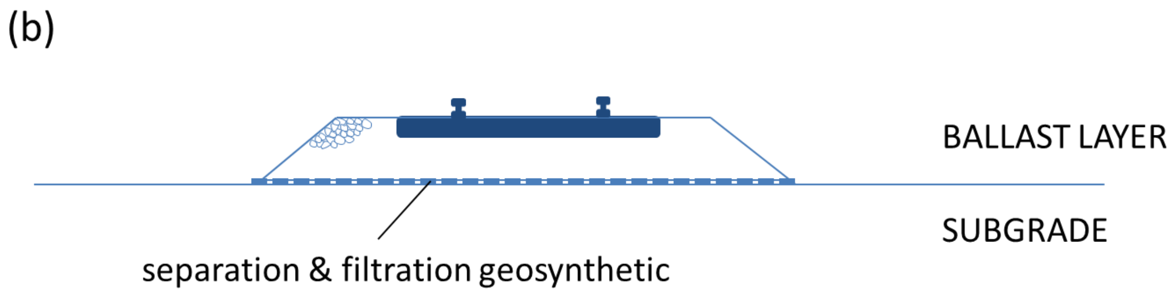


Figure 1: Separation & filtration geosynthetic might be placed (a) beneath the formation layer or (b) directly beneath the ballast layer.

In the case whereby the separationand filtration geosynthetic is not designed using detailed analysis, empirical recommended values of its essential characteristics are outlined in Table 4.

Table 4: Recommended values of essential characteristics for separation and filtration geosynthetic (values in brackets are recommended if reinforcing geosynthetic is used at the same time)

Function		Recommended value	Test method
Mechanical characteristics			
Tensile strength	kN/m	≥20 (6)	EN ISO 10319
Elongation at maximum load	%	≥60	EN ISO 10319
Tensile strength at strain 2%, 5%, 10%	kN/m	≥1/2/4 (0.5/1/2)	EN ISO 10319
Static puncture (CBR test)	N	≥3000 (2000)	EN ISO 12236
Dynamic perforation resistance (cone drop test)	mm	≤15	EN 918
Durability	Decrease of tensile strength for ≤ 20%		EN 12224 EN 14030
Hydraulic characteristics			
Characteristic opening size (O_{90})	mm	$0.08<O_{90}<0.12$	EN ISO 12956
Water permeability normal to the plane	lm^2/s	≥50	EN ISO 11058
In-plane flow capacity[1]	m^2/s	$\geq 40\times10^{-7}$	EN 12958 i=1

It is recommended to combine separation and filtration geosynthetics with reinforcing geosynthetics. Normally, any kind of geogrid might be used. At the SMART RAIL project test site, a geocomposite has been used (Figure 2) - separation and filtration geosynthetics are attached to the geogrid.

Figure 2: Construction of test site in Sava exit (Slovenia) for SMART RAIL project. Placement of geocomposite at the top of the subgrade.

[1] This characteristic is not essential as lateral draining is performed through coarse material in the upper layers

2.5 Sub-ballast (formation) layer

The main aim of the formation layer is to improve the bearing capacity of track formation in the case of a soft subgrade soil. The material used within the formation layer has to fulfill requirements regarding frost resistance and in-plane draining of pore water from the subgrade.

When track design includes a formation layer, it is recommended to use material with grading within the following requirements:

- for draining capability (based on the separation criteria adopted from Terzaghi (1925))

$$4 \times d_{15} \leq D_{15} \leq 4 \times d_{85},$$

where
d_{15} … means particle sizes corresponding to 15 percent finer by dry weight from the gradation curve of the subgrade soil,
d_{85} … = particle sizes corresponding to 85 percent finer by dry weight from the gradation curve of the subgrade soil,
D_{15}… = particle sizes corresponding to 15 percent finer by dry weight from the gradation curve of the material for the formation layer.

- for frost resistance

if percent finer than 0.02 mm is <3% → C_u>15,
if percent finer than 0.02 mm is <10% → C_u>15,

where

$$C_u = D_{60} / D_{10},$$

and
D_{60} … = particle sizes corresponding to 60 percent finer by dry weight from the gradation curve of the material for the formation layer,
D_{10} … = particle sizes corresponding to 10 percent finer by dry weight from the gradation curve of the material for the formation layer.

2.6 Geosynthetic reinforcement

The ballast bed consists of a layer of loose, coarse grained material which, as a result of internal friction between the grains, can absorb considerable compressive stresses, but not tensile stresses (Esveld, 2001). Therefore, the bearing strength of the ballast bed in the vertical direction is considerable, while it is clearly reduced in the lateral direction. Thus reinforcing is recommended beneath the ballast layer.

Therefore, subgrade has to exhibit a sufficient bearing capacity (recommended E_{v2}>20 MPa), and has to be consolidated (compaction > 97% Proctor). In addition, its profile should not deviate more than 10 mm from design profile. To promote better stress distribution and provide protection against frost, a sub-ballast (formation) layer is placed between the ballast bed and the subgrade. In the case of very soft subgrade soil, additional reinforcement beneath the sub-ballast layer is recommended to fulfill the railway design requirements for formation bearing capacity according to the type of track. Empirical recommended values for essential characteristics of geosynthetic (geogrid) reinforcement placed beneath the sub-ballast (formation) layer are listed in Table 5.

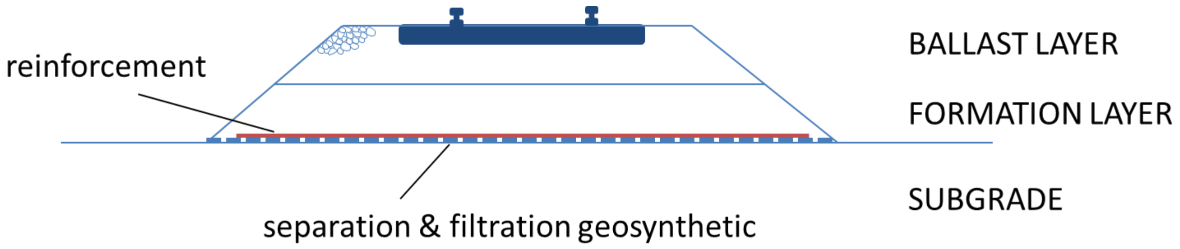


Figure 3: Reinforcing geosynthetics placed beneath the formation layer

Table 5: Recommended values of essential characteristics for reinforcing geogrid beneath the formation layer

Characteristic		Recommended value	Test method
Tensile strength in transversal (longitudinal) direction	kN/m	≥ 40 (30)	EN ISO 10319
Tensile strength in two main directions at strain 2%	kN/m	≥ 10 (7)	EN ISO 10319
Aperture size, *s*	mm	20 ≤ *s* ≥ 40	
Durability	kN/m	tensile strength after exposure ≥ 40 (30)	EN 12224 EN 14030
Abrasion resistance	%	75	EN ISO 13427

The SMART RAIL project has enabled the long term monitoring of the deformation behaviour of the geogrid installed at the top of the subgrade. No essential creeping has been observed in the five years since installation at normal railway. The Geogrid was installed at a depth of 1 m below the sleeper.

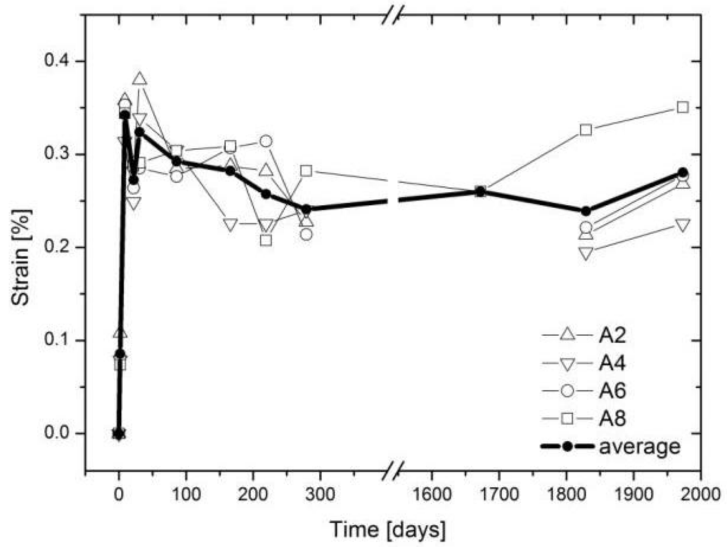


Figure 4: Strain of geogrid at depth of 1.0 m below the sleeper measured in transversal direction over a period of 5 years. Test section Dolga Gora (Slovenia), SMART RAIL project

When no sub-ballast layer is needed, reinforcing is performed directly beneath the ballast layer. In this instance, combining the reinforcement with separation and filtration geosynthetics is mandatory. One should also keep in mind two important issues regarding the depth and survivability of geosynthetics during installation, which were referred to at the beginning of this guideline.

The empirical recommended values for essential characteristics of geosynthetic (geogrid) reinforcement placed beneath the ballast bed are listed in Table 6.

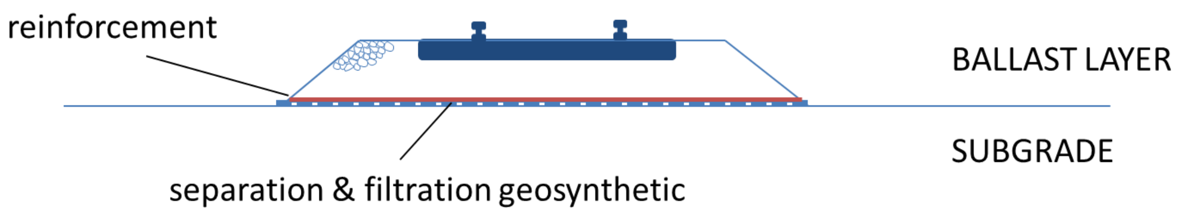


Figure 5: Reinforcing geosynthetics placed beneath the ballast layer

Table 6: Recommended values of essential characteristics for reinforcing geogrid beneath the formation layer

Characteristic		Recommended value	Test method
Tensile strength in transverse (longitudinal) direction	kN/m	≥ 40 (30)	EN ISO 10319
Tensile strength in two main directions at strain 2%	kN/m	≥ 15 (10)	EN ISO 10319
Aperture size	mm	1.4 x d_{50}	
Durability	kN/m	tensile strength after exposure ≥ 40 (30)	EN 12224 EN 14030
Abrasion resistance	%	90	EN ISO 13427

4. Reference documents relating to the SMARTRAIL project

- Deliverable 3.1 European Existing Railway Tracks A Survey Report
- Deliverable 3.2 Rehabilitation of Open Tracks and Transition Zones