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Guide for Barriers when Using Soils and Construction Materials with Environmentally Sensitive Contents

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Abstract: On 16 July 2021, the German "Mantelverordnung" (Construction Materials Regulation) was published in the *Federal Law Journal.* From August 1, 2023, this regulation is to be applied nationwide and, for the first time, regulates legally nationwide binding requirements for mineral construction waste and its use in technical structures. It also refers to specific construction methods with construction waste material. In the course of the construction of infrastructure traffic routes, it is possible to use these construction materials with limited contamination for the construction of, e.g., noise barriers, dams or embankments. The German M TS E (Merkblatt über Bauweisen für Technische Sicherungsmaßnahmen beim Einsatz von Böden und Baustoffen mit umweltrelevanten Inhaltsstoffen im Erdbau) Guideline of the FGSV (Road and Transportation Research Association) lists various alternatives for barriers in such structures. Geosynthetic barriers, e.g., GCLs (Geosynthetic Clay Liners, also known as bentonite mats) or polymeric geomembranes as well as other geosynthetics can have economic and design advantages over conventional mineral barriers. Depending on the proposed construction method, the guideline sets out certain requirements, not only but also for permittivity and confining stress. In the following, the construction methods in general and the design solutions with GCLs in particular are presented.

Key words: Construction waste, geosynthetic barriers, GCLs, barrier construction methods.

1. A Regulation for the Re-use of Construction Waste Material

In June 2021, the German Substitute Construction Materials Regulation (Ersatzbaustoffverordnung, also called "Mantelverordnung") [1] was passed and will come into force in August 2023. With this law, politicians want to promote the re-use of mineral construction waste, among other things. Since this waste is often used in road construction and earthworks, the protection of soil and groundwater is strengthened at the same time on a national level.

According to the latest monitoring report on mineral construction waste [2], a total of 218.8 million tonnes of mineral construction waste was generated in Germany in 2018. Then, already 90% of the 218.8 million tonnes of mineral construction waste was reused but, in most cases, by means of down cycling. About 10% of the soils and stones (e.g., excavated soil, excavated material, track ballast) were used for the production of recycled construction materials. However, the main part of this construction waste ended up as backfill material. Concrete, brick and tile construction waste was primarily processed into bulk materials for road and earth construction.

If large quantities of the mineral construction waste are reused for near-earth applications, it should at least be ensured that no environmental sensitive contents are released into the surrounding area as a result. Therefore, one of the main objectives of the "Mantelverordnung" is to establish requirements for the protection of soil and groundwater. These already existed before, but not in a nationwide uniform manner.

Section 2 of the Substitute Construction Materials Regulation defines in detail what is covered by the term "substitute construction material". This means any mineral construction material which is produced

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as waste or as a by-product in processing plants or which accumulates during construction measures, e.g., demolition, conversion, expansion, new construction and maintenance and which is suitable and intended for installation in technical structures, either directly or after processing.

Specifically, the new German "Substitute Construction Materials Regulation" names the following types of substitute construction materials: recycled construction materials, excavated material, track ballast, brick material, soil material, different slag materials, copper smelter material, foundry residual sand, smelting chamber granulate from the firing of hard coal, hard coal boiler ash, hard coal fly ash, lignite fly ash and household waste incineration ash.

Depending on local conditions, the regulation prescribes certain installation methods for the users of substitute construction materials in order to minimise the entry of residual pollutants into the soil and groundwater through leachate. The regulation thus specifies for all parties involved with the conditions under which the use of substitute construction materials in technical structures will be considered harmless to humans and the environment in the future.

At the same time, it is clear that this regulation wants to support and promote the goals of the circular economy and improve the acceptance of substitute construction materials.

2. Re-use of Soils and Construction Materials with Environmentally Sensitive Contents

The use of excavated soil, construction waste products and recycled construction materials in earthworks contributes to the conservation of resources and the currently necessary reduction of landfill space. Nevertheless, there is a special need for action for the selection of technical safety measures which are necessary for the use of soils and construction materials with environmentally relevant contents (so-called substitute construction materials).

In its current version [3], the Code of Practice on Construction Methods for Technical Safety Measures when Using Soils and Construction Materials with Environmentally Sensitive Contents in Earthworks (M TS E) regulates various construction methods that can be used as technical encapsulation measures.

The new German "Substitute Construction Materials Regulation" [1], starting on 1 August 2023, is intended to create for the first time nation-wide and legally binding requirements for the recycling and re-use of mineral waste. It also refers to technical structures using soils and construction materials and construction methods following the current German M TS E guide and therefore makes this guide into a law.

Criteria such as construction costs, service life and susceptibility to repairs are decisive in the selection of construction materials. The use of geosynthetics can be highly efficient, not least due to the comparatively simple installation conditions of the industrially manufactured and quality-assured roll material.

3. Technical Barrier Safety Measures in Road Construction

3.1 Contents of the M TS E Guide

The contents of the M TS E guide are so-called standard construction methods with material- and manufacturing-related requirements for barrier components as well as requirements for quality control and monitoring during construction.

The following infrastructure construction methods, roughly outlined in keywords below, are proposed in the M TS E. The following requirements for barrier components are also included in the M TS E. The term "weather-sensitive" is used for materials which react with a certain sensitivity to desiccation and frost stresses. Weather sensitivity is mainly characterised by the fact that the water content of a barrier element has a significant influence on its sealing efficiency. Consequently, a mineral barrier component such as a clay liner or a GCL (Geosynthetic Clay Liner), also known as bentonite mat or GBR-C (clay geosynthetic barrier), can be assigned to the weather-sensitive barrier systems. A weather-induced influence on the efficiency of these barrier types is not expected for construction methods A and B due to the fact that the required cover soil thickness over the barrier is 1.5 m. However, the required thickness of 1.5 m can be reduced to 1.0 m according to the M TS E guide for products with a suitability verification from a design engineer.

A barrier element that is insensitive to weather effects is a polymeric geosynthetic barrier (geomembrane). Construction method C requires such a weather-insensitive barrier type, such as a polymeric geomembrane or a multi-component GCL.

The construction methods described in sections 3.1.1-3.1.6 (construction methods A-E) can be used as technical securing measures. Depending on the local conditions and the earthworks properties of the material to be secured, a suitable construction method can and must be selected. Examples of construction methods are recommended for the main area of application of road embankments (with an “impermeable” road pavement on the crest, Fig. 1, top) and protective embankments (walls, Fig. 1, bottom), but they can also be applied to other earthworks. The following main focuses are construction methods with road pavements on the crest.

3.1.1 Construction Method A

This construction method requires a weather-sensitive barrier component without an overlaying drainage layer (rainwater collection system) and with a cover soil layer. In the case of construction method A, the barrier layer can be either a 50 cm thick compacted clay liner or a GCL (Fig. 2). The general system requirements are:

- Covering of the weather-sensitive or root-penetration sensitive barrier layer with 1.5 m cover soil material (can be product-specific reduced to 1.0m) and a top vegetation layer;
- The cover soil must be at least 1,000 times more permeable than the weather-sensitive barrier element ($\Delta k > 1\times10^3$ m/s);
- Permeability coefficient of the barrier element: Equivalent to $k < 5\times10^{-10}$ m/s (50 cm thick).

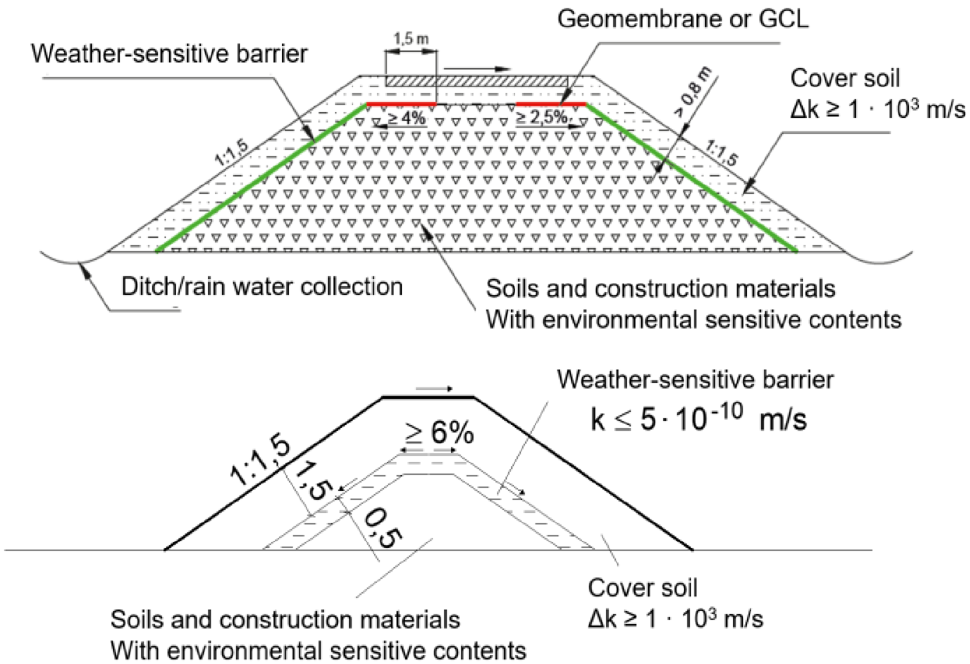

Fig. 1 Embankments according to construction method A with (top) and without (bottom) a road pavement on the crest.

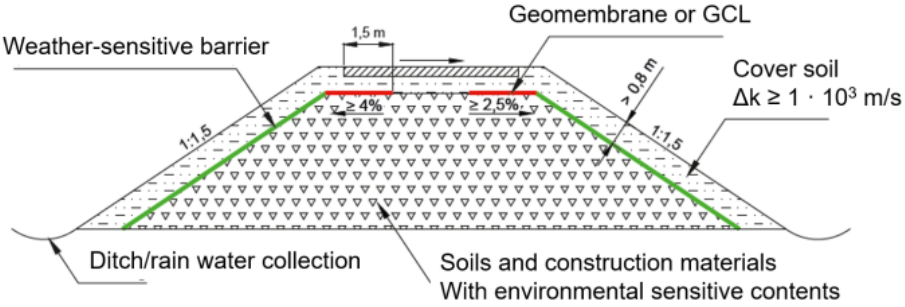

Fig. 2 Cross-section for an embankment according to construction method A with a weather-sensitive geosynthetic barrier without a rainwater drainage collection layer.

3.1.2 Construction Method B

This construction method requires a weather-sensitive barrier element with a drainage layer (rainwater collection system) on top of the barrier element (Fig. 3). Due to this drainage layer, there is a different requirement for the permeability coefficient of the barrier element. Further, there are no permeability requirements for the cover soil layer. The general system requirements are:

- Covering of the weather-sensitive or root-penetration sensitive barrier layer with 1.5 m cover soil material (can be product-specific reduced to 1.0 m) and a top vegetation layer;
- Permeability coefficient of the barrier element: Equivalent to $k < 5\times10^{-9}$ m/s (50 cm thick).

3.1.3 Construction Method C

The main aspect of this construction method (Fig. 4) is to reduce the cover soil thickness as required in the methods A and B. This requires a barrier type that is insensitive to weather effects, such as a geomembrane or a multi-component GCL. The general system requirements are:

- The cover soil thickness is not quantified and needs to be determined project-specific;
- The barrier system is insensitive to weathering (e.g., geomembrane, multi-component GCL).

3.1.4 Construction Method D

With this construction method, an additional barrier element is not required, if the environmentally sensitive embankment fill material is capped with a paved (long-term impermeable) road (Fig. 5). However, this method is not suitable if built on soils that are susceptible to settlements. The general system requirements are:

In general, the cover soil permeability k_1 should be 50 times more permeable than the permeability k_2 of the waste core ($k_1 \geq 50\times k_2$) or $k_1 \geq 1\times10^{-4}$ m/s;

The soil/waste core may not exceed vertically the sealed pavement over the base course and capillary water transport into the waste core must be prevented;

Impermeable paved layer on the crest.

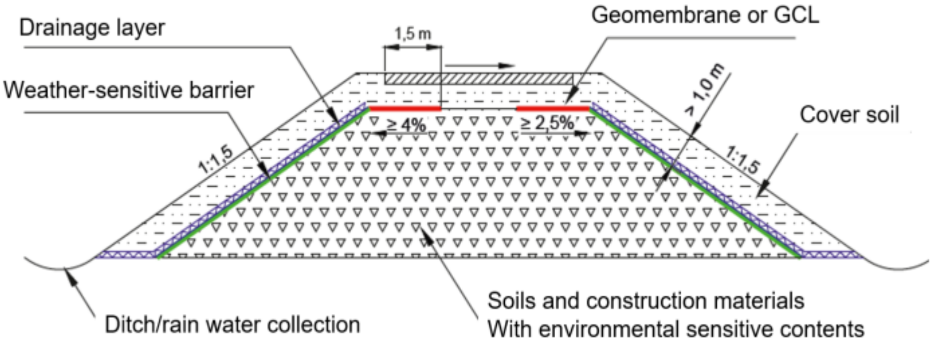

Fig. 3 Cross-section for an embankment according to construction method B with a weather-sensitive geosynthetic barrier and a rainwater drainage collection layer.

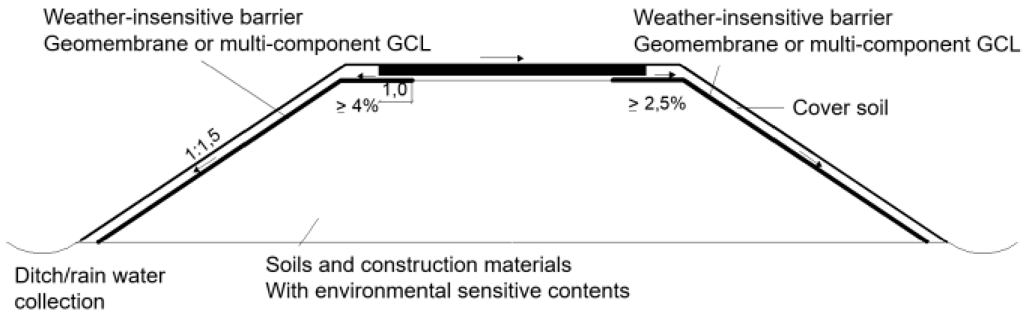

Fig. 4 Cross-section for an embankment according to construction method C with a weather-insensitive geosynthetic barrier.

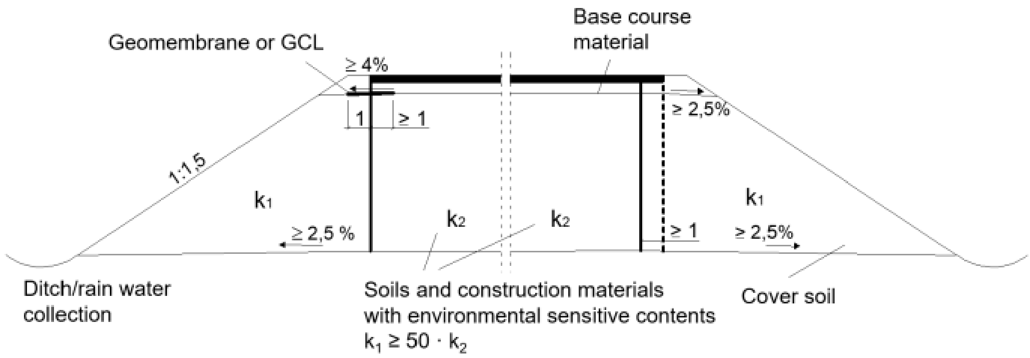

Fig. 5 Cross-section for an embankment with a waste material core according to construction method D (leftpart, version 1 with a geomembrane or GCL strip; right part, version 2 with an indented core) to prevent capillary water transport.

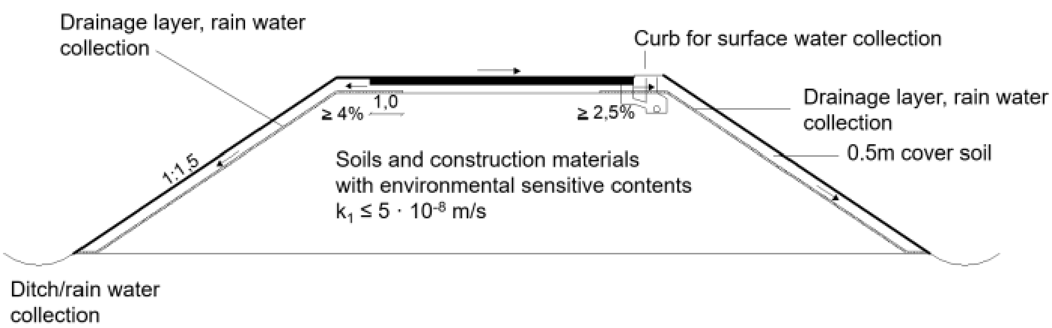

Fig. 6 Cross-section for an embankment according to construction method E (system 1) with low permeable waste material.

3.1.5 Construction Method E (System 1)

This construction method is based on the construction of the entire dam or embankment from a comparatively low permeable soil or construction waste MESC (material with environmentally sensitive contents). In this method, no barrier element is required. However, the design must consider a drainage layer on the slopes and a curb in the road to collect the paved road surface water (Fig. 6).

The general requirements are:

- Permeability coefficient of the environmentally sensitive fill material: $k < 5\times10^{-8}$ m/s;
- A higher curb for the prevention and collection of road surface water run-off;
- Placement of a drainage layer on the side slopes;
- Impermeable paved layer on the crest.

3.1.6 Design E (System 2)

This construction method is based on the construction of the entire dam or embankment from a comparatively low permeable soil or construction waste MESC (Fig. 7).

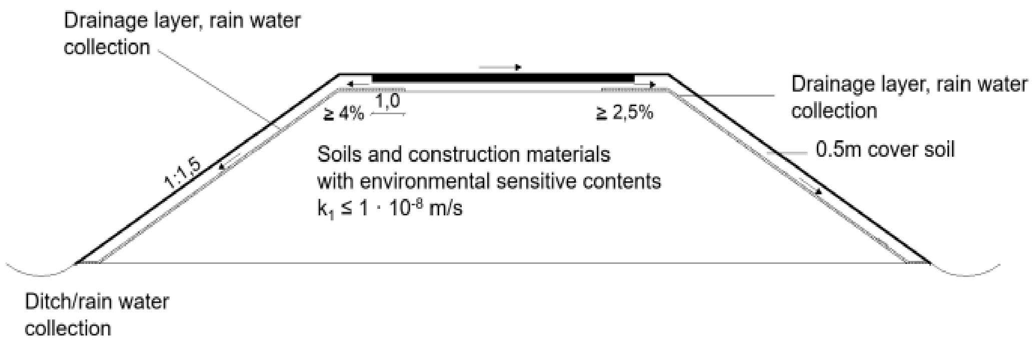

Fig.7 Cross-section for an embankment according to construction method E (system 2) with low permeable waste material.

However, the requirement for the permeability coefficient is more stringent by half of an order of magnitude, compared to design E (system 1). Therefore, the water from the paved road surface can flow freely over the slopes of the dam or embankment. In this method, no barrier element is required. However, a drainage layer for rainwater and road water run-off collection is required on the slopes. The general requirements are:

- Permeability coefficient of the construction fill MESC: $k < 1 \times 10^{-8}$ m/s;
- Impermeable paved layer on the crest.

4. Barrier with Geosynthetic Clay Liners

4.1 Use of Geosynthetic Barriers as a Construction Method for Earth Structures with Soil or Waste Materials with Environmentally Sensitive Contents

In principle, the durability of all components in environmental protection applications must survive the planned service life. If the durability of the geosynthetic barrier element should pass 100 years, polymeric geomembranes in Germany fulfill this requirement if they have the German BAM (Bundesanstalt für Materialforschung und -prüfung) approval and GCLs have the German LAGA (Bund/Länder-Arbeitsgemeinschaft Abfall) suitability assessment.

Safety measures according to the requirements of the M TS E guide are construction methods which are suitable to protect the surrounding soils, environment, groundwater and rainwater run-off from the road if soils and construction materials with environmentally relevant contents are used. Barrier systems naturally play an important role here. They therefore consist of the barrier element itself, e.g., a geosynthetic clay liner (GCL), a polymeric geomembrane barrier, as well as any necessary drainage, protection, separation, filtration or reinforcement layer, for which geosynthetics are often used. A GCL is particularly suitable for construction methods A and B for the barrier component, multicomponent GCLs and geomembranes for construction method C.

Even though construction methods D and E do not require a barrier element, the main risk of these construction methods is the water infiltration into the embankment fill from the side slopes, causing a leaching of environmentally sensitive contents. Adding a geosynthetic barrier in the design would improve the performance of these solutions immensely.

Pavements made of asphalt or concrete materials are generally regarded as impermeable or watertight. For this reason, the current M TS E guideline does not specifically recommend a barrier under the sealed pavement. However, it is questionable if sealed pavements would fulfil the same 100-year durability as requested for a geosynthetic barrier. To be on the safe side, an additional barrier should then be installed under the paved road in all construction methods, using a geomembrane or a GCL.

4.2 Water Permeability

In order to be able to compare mineral materials of different thicknesses (e.g., a compacted clay liner with a considerably thinner GCL), the water permeability as stated in current regulations and guidelines is calculated to a permittivity value ψ_d (s^{-1}). The water permeability coefficient (k value) is related to the thickness of the barrier layer. The permittivity is thus the quantity of water V_W that passes through the barrier element per time unit Δt, water level height difference Δh and area unit A.

$$With \quad \psi = \frac{k}{d} \quad results$$

$$\psi = \frac{Vw}{A \cdot \Delta h \cdot \Delta t} \; [s^{-1}] \qquad (1)$$

The design value of the permittivity is calculated:

$$\psi_{d\,GCL} = A_1 \cdot A_2 \cdot \psi_c < \psi_{req} \qquad (2)$$

With:

Ψ_c = characteristic permittivity (s^{-1}) of the virgin produced GCL as 95% fractile value from statistical evaluation of product monitoring (manufacturer's specification);

$\Psi_{d\ GCL}$= design value of permittivity (s^{-1}) for the GCL permittivity exposed to the corresponding reduction factors;

A_1 = reduction for change of barrier properties at overlaps/joints (manufacturer's specifications, usually approx. 1.0-1.1);

A_2 = reduction for change of barrier properties of bentonite by cation exchange (manufacturer's specifications, usually about 4.0-6.0);

k = water permeability (m/s);

V_w = quantity of water (m^3);

Δt = measuring time (s);

Δh = standpipe water head difference (m);

A = cross-sectional permeation area (m^2);

d = permeated layer thickness (m).

Commercially available GCLs typically have permittivities of approx.

$\Psi_{GCL} \leq 5 \times 10^{-9}$ (s^{-1}) (as delivered).

4.3 Efficiency and Cover Soil

According to the M TS E guide, a 1.5m thick cover soil is in general necessary to protect the weather-sensitive barrier in construction method A and B from any possible effects that likely could affect the overall system performance. These could be caused by desiccation, freezing/thawing, root penetration, too low confining stress (e.g., 0.4 m soil thickness) or other effects. However, the selected recommended cover soil thickness is thicker than typically seen in landfill cap sealing systems. Therefore, the guideline allows a reduction of the cover soil thickness to 1.0 m, if the performance efficiency is maintained, with a suitability verification from a design engineer.

A reduction of this quoted cover soil thickness is e.g. acceptable if the barrier system efficiency with thinner cover soil thicknesses has been demonstrated, e.g. in long-term real life field trials (e.g. > 15 years). This applies, for example, to the products investigated since 1999 until today and documented in Ref. [4].

The measurement and evaluation of the water quantities from precipitation, drainage and permeation are investigated under real-life *in-situ* conditions within a modern lysimeter field trial in Lemförde, Germany. By suitable variation of the test parameters (type of cover soil, confining stress, bentonite grain size (powder or granular)), it is clearly shown that a long-term system effectiveness of 99% is achieved for the investigated GCL products with a cover soil thickness of 1.0m, however, only with powder bentonite as sealing layer in the GCL. This soil cover thickness is normally also sufficient to protect the GCL from desiccating and freezing effects, so that the required performance is achieved. With a multi-component polyethylene-coated GCL, the reliability and performance of the barrier system is significantly increased. This additional PE (polyethylene) barrier should be placed on the top side to protect the bentonite layer from, e.g., desiccation, affecting chemicals or root penetration.

Based on these interrelationships, there are recommendations for the cover soil thicknesses in M TS E applications to ensure the barrier performance:

- for GCL with PE coating: 0.8 m;
- for GCL without PE coating: 1.0 m.

For all construction methods an additional geosynthetic barrier element (geomembrane or GCL) under the paved roadway should be considered to improve the overall performance, especially in case of an expected permeation through the paved section or infiltration from the side of the construction, as already stated in chapter 4.1.

4.4 Use of a GCL for Construction Method A

According to chapter 5.5 of the M TS E guide, a GCL can be assumed as efficient as a compacted clay liner if it meets the same permittivity ψ (s^{-1}) value.

The required compacted clay permittivity is $\psi_{req} = 2.7\times10^{-9}(s^{-1})$ for the construction method A (with $k = 5\times10^{-10}$ m/s, thickness d = 0.5 m and with a constant water head of 0.3 m).

The permittivity comparison is done based on the short-term permeability value of a compacted clay liner, whereas the permittivity value of the GCL is calculated with long-term reduction factors. The authors do not believe that a compacted clay liner would achieve these values in long-term field conditions.

According to the German LAGA suitability certificate [5], the design value, taking into account material variation and effects during installation and long-term performance (>100 years), results in

$$\Psi_{d\ GCL} = 1.76\times10^{-8}\ s^{-1} \qquad (3)$$

Thus, the use of a stand-alone GCL is initially not possible, at least with the above-mentioned approach.

However, a multi-component GCL can be installed as a barrier element in construction method A as a weather-sensitive barrier element and will maintain the above-mentioned requirements. A multi-component GCL is, e.g., a regular GCL with a PE barrier applied to the entire surface of the woven carrier layer as an extruded coating.

The extruded PE coating provides the necessary protection against desiccation and root penetration. Additionally, the PE coating improves the sealing performance of the GCL as it utilises the best of both synthetic and natural materials, achieving a long-term permittivity value ψ_{req} several orders of magnitude lower than 2.7×10^{-9} (s^{-1}). Accordingly, only sufficient protection against freezing conditions might be necessary, which can be achieved with a cover soil thickness of ≥1.0 m depending on the frost protection zone.

4.5 Use of Geosynthetics for Construction Method B

The fundamental design difference between construction method B and A is the arrangement of a rainwater collection layer (e.g., geosynthetic drainage mat) above the barrier element. This rainwater collection drainage system now allows the use of nearly any type of cover soil material and does not request a certain soil permeability value as in construction method A. The cover material can be selected on a project-by-project basis with regard to the parameters of availability and cost-effectiveness. Furthermore, the permeability/permittivity requirement of the barrier element (compared to construction method A) is one order of magnitude higher.

According to the M TS E guide, a GCL can be assumed as efficient as a compacted clay liner if it meets the same permittivity ψ (s^{-1}) value. The permittivity comparison is again done based on the short-term permeability value of a compacted clay liner, whereas the permittivity value of the GCL is calculated with long-term reduction factors. The authors do not believe that a compacted clay liner would achieve these values in long-term field conditions.

The required compacted clay permittivity is $\psi_{req} = 2.7\times10^{-8}$ (s^{-1}) for the construction method B (with $k = 5\times10^{-9}$ m/s, thickness d = 0.5 m and with a constant water head of 0.3 m).

According to the German LAGA suitability certificate [5], the design value, taking into account material variation and effects during installation and long-term performance (>100 years), results in

$$\Psi_{d\ GCL} = 1.76\times10^{-8} s^{-1} \quad (4)$$

The use of this GCL barrier element is therefore permissible.

A geosynthetic drainage element is placed directly above the barrier layer. It is recommended to incorporate a dimensioned nonwoven filter and separation geotextile on the drainage core in direct contact with the cover soil material. Due to the likely steeper slopes in this application, the interface friction properties might be critical, so that needle-punched nonwoven geotextiles might be the better option. Additionally, the drainage capacity of the drainage element, the installation resistance as well as filter stability and likely the protection efficiency should be considered when selecting the proper geosynthetic drainage element. The durability of these elements must also be demonstrated over the intended service life. For products with a German BAM approval according to the German "Guideline for the approval of geosynthetic drainage elements for landfill surface barrier", a durability of at least 100 years can be assumed. With a CE (Conformité Européenne) mark valid for the relevant field of application, proof of up to 100 years can be provided.

4.6 Use of Geosynthetics for Construction Method C

For construction method C, a polymeric geomembrane with a thickness of ≥ 2.5 mm can be used as a weather-resistant barrier element. The cover soil thickness is not quantified and needs to be determined on a project-specific basis.

Alternatively, a PE-coated multi-component GCL as already described for construction method A can be accepted. To ensure a long-term durable lining system, the cover soil thicknesses should be ≥ 0.8 m.

4.7 Use of Geosynthetics for Construction Methods D and E

Initially, no barrier systems are recommended for these construction methods. However, for construction method E drainage layers are required on the slopes to collect rainwater and road run-off water.

In addition, with regard to the information already stated in chapter 4.1, an additional geosynthetic barrier element (geomembrane or GCL) under the paved roadway should be considered to improve the overall performance, especially in case of an expected permeation through the paved section or infiltration from the side of the construction.

4.8 Use of Geosynthetic Reinforcement for Slope Stabilisation

Barrier systems usually require special slope stability verifications in the system layers and interfaces to prevent a sliding between or in the layers. Experience has shown that additional geosynthetic reinforcement elements, e.g., geogrids (Fig. 8), may be required for slopes steeper than 1:2.5 in order to ensure the slope stability.

5. Recommended GCL Properties

It is recommended to set minimum requirements for a GCL in order to ensure long-term performance. The following listed specification values are therefore recommended as they follow the German M TS E requirements, the generic German STLK [6] and the GRI-GCL3 [7] recommendations.

Fig. 8 Use of a geogrid reinforcement in construction method B for encapsulation of MESCs on a 1:1.5 (*v*:*h*) slope for slope stabilisation.

5.1 GCL

• GCL consisting of two bentonite-encapsulating geosynthetics (Fig. 9): a polypropylene (PP) carrier woven (≥ 100 g/m^2) and cover nonwoven (≥ 200 g/m^2);

• Layer of sodium bentonite powder encapsulated between two geosynthetic layers; bentonite mass per unit area ≥ 3,700 g/m^2 at max. 15% water and a free swell value ≥ 24 mL following ASTM D5890;

• Uniform shear stress transferring needle-punching through the two bentonite-encapsulating geosynthetics creating a shear strength transmitting GCL with a peel strength (ASTM D6496) of ≥ 360 N/m;

• GCL tensile strength (EN ISO 10319 or ASTM D6768) longitudinal/transverse 10 kN/m;

• Self-sealing, 30 cm wide length overlaps with bentonite impregnated during the manufacturing process;

• Required service life over 100 years confirmed by a LAGA suitability certificate;

• Permittivity (Ψ_{GCL}) 5×10^{-9} s^{-1} (ASTM D5887 or EN ISO16416).

5.2 GCL with Additional Polymer-Coated Barrier

• PE extrusion-coated, multi-component GCL consisting of two bentonite-encapsulating geosynthetics (Fig. 10): a polypropylene (PP) carrier woven (≥ 100 g/m^2), a cover nonwoven (≥ 200 g/m^2) and a smooth PE barrier (≥ 200 g/m^2) firmly attached to the woven geosynthetic;

• On embankment slopes, the PE barrier attached to the woven geosynthetic should be structured and have a mass per unit area of ≥ 500 g/m^2;

• Nod heights of the embossed structured PE surface: 80% ≥ 0.4 mm;

• Layer of sodium bentonite powder encapsulated between two geosynthetic layers; bentonite mass per unit area ≥ 3,700 g/m^2 at max. 15% water and a free swell value ≥ 24 mL following ASTM D5890;

• Uniform shear-stress transferring needle-punching through the two bentonite-encapsulating geosynthetics creating a shear strength transmitting GCL with a peel strength (ASTM D6496) of ≥ 360 N/m;

• GCL tensile strength (EN ISO 10319 or ASTM D6768) longitudinal/transverse 10 kN/m;

• Self-sealing, 30 cm wide length overlaps with bentonite impregnated during the manufacturing process;

• Required service life of the GCL without coating over 100 years confirmed by a LAGA suitability certificate;

• GCL (without coating) permittivity (Ψ_{GCL}) ≤ 5×10^{-9} s^{-1} (ASTM D5887 or EN ISO16416);

• Calculated permeability of coating (k_{10}) (EN 14250): ≤ 10^{-14} m/s.

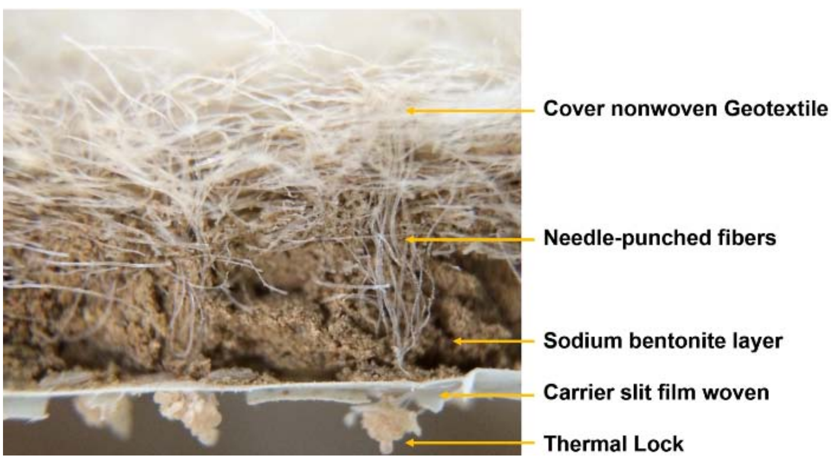

Fig. 9 Cross-section of a needle-punched GCL.

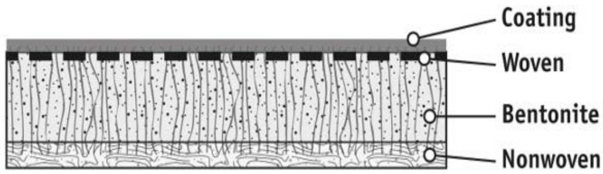

Fig. 10 Cross-section of a PE-extrusion coated GCL (multi-component GCL) needle-punched GCL.

6. Quality Assurance/Contractual Issues

When using geosynthetics, the installation guide-lines of the supplying manufacturer should be available on site and of course be followed. GCL aspects such as direction of placement, overlap issues, cover soil placement, concerns of unconfined bentonite hydration or use of pre-hydrated GCLs must be taken into account, typically already in the design and specification stage.

For geosynthetics in general, in Europe the CE marking has been applied since 2002, for geosynthetic barriers since 2005. The person who places the product on the market in the European Union is responsible for ensuring that a geosynthetic is provided with a CE mark. The corresponding standards define a uniform testing technique and documentation for defined characteristic values in connection with the respective application (e.g., road construction). This implicates a corresponding quality assurance (monitoring of the manufacturer, external monitoring by a Notified Body).

Additionally, it is recommended that quality control and assurance tests are done site-specific, including material testing, supervision of geosynthetic installation and soil placement.

On-site design suitability test (can also be referred to as on-site design acceptance testing) should also be required and carried out by the owner/operator/client. The project-specific suitability should e.g., include design friction values between the geosynthetic(s) and the on-site soil materials, as well as among others the protection efficiency (in case of recommended geosynthetic protection layers). These tests cannot be carried out as laboratory index tests, but must be related to the project-specific conditions, e.g. with the site-specific soil and geosynthetic materials.

The product quality assurance (acceptance) testing, which is carried out by the contractor, includes verification of the product identity and the product properties (checking the requirement values or classes specified in the construction contract, checking the proof of the environmental declaration, etc.). Each delivered geosynthetic roll should have a unique manufacturing roll number. These should be noted and listed in an installation plan. This is to ensure any necessary identification and traceability. In addition to the mentioned roll number, this must contain information on the manufacturer, product name, product type, etc.

7. FE Modelling of Different M TS E Construction Methods

Within the scope of the research described in Ref. [8], the various construction methods were evaluated with regard to their effectiveness. In this research report [8], calculations were presented to investigate the effectiveness of different construction methods for the technical protection of soils and waste materials with environmentally relevant substances in earthworks. Numerical calculations with the FEFLOW flow simulator were carried out to investigate the effectiveness of the various construction methods. Based on preliminary investigations, the influence of different materials in the area of the road structure (embankment and topsoil) was analysed. Based on the preliminary investigations, a situation of the road structure was defined, which was then used to carry out the further calculations to determine the seepage quantities to be expected with the different construction methods. Using a large number of calculations, various scenarios were investigated with regard to the precipitation occurring and the soil characteristics on which the various layers are based. To determine the effectiveness of the different construction methods, the amounts of water flowing into and out of the soils and building materials

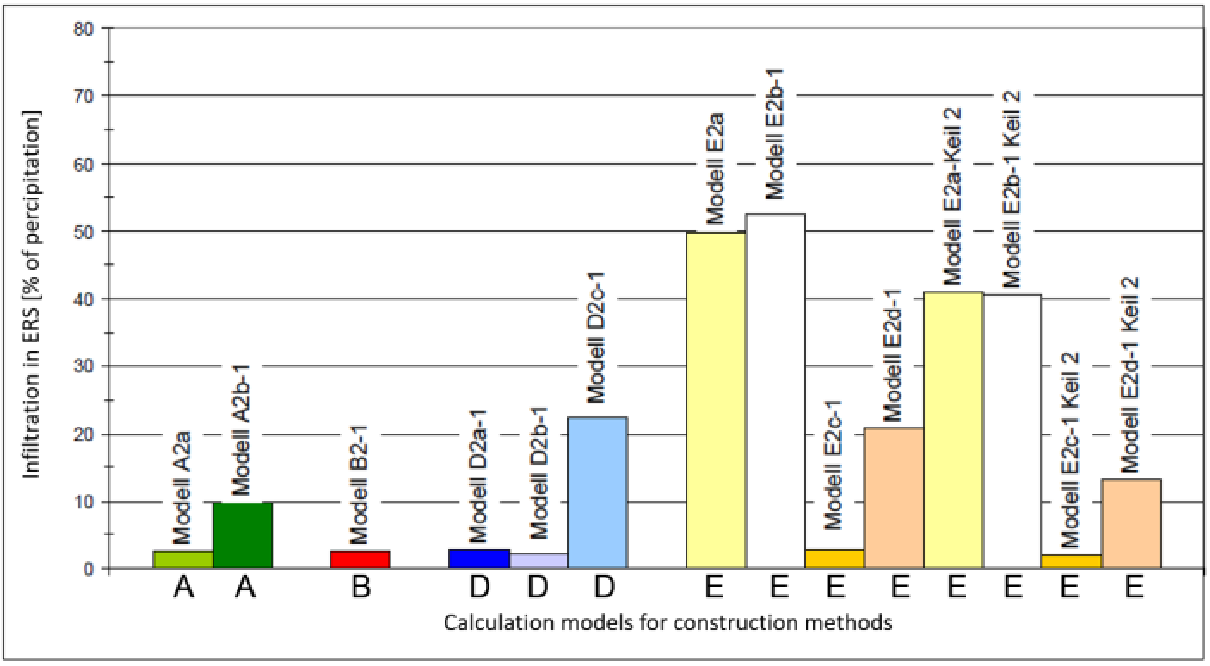

Fig. 11 Infiltration in MESC related to precipitation in steady state flow for construction methods A, B, D and E for a simulated precipitation of 2.35 mm/day [8].

containing environmentally relevant substances were analysed for the individual models. In order to ensure the comparability of the results, the steady-state flow condition was considered in each case. Due to the partly very high calculation effort, this could not be achieved in all model calculations. In this case, the seepage quantities to be expected in the steady state were extrapolated from the available data. By comparing the seepage quantities to be expected for the different construction methods, it was possible to evaluate the construction methods presented in the M TS E. The causes for the comparatively large water quantities determined for individual construction methods were discussed and possible constructive measures presented. However, not all construction methods could be conclusively evaluated. The results showed that the actual conditions with the temporally constant precipitation defined in the calculations are only reflected to a limited extent. It is assumed that the quantities of seepage water infiltrating into the soils and waste materials with environmentally sensitive contents are maybe overestimated. Further investigations on this topic are being carried out.

Even though the results are only based on a model, it does show a trend for the efficiency of the construction methods. The first statement is that, similar to a landfill cap, a drainage layer efficiently reduces infiltration of rainwater into the MESC and therefore increases the efficiency of the barrier system (see method B in Fig. 11). Additionally, the construction methods with barriers (A and B) seem to be most efficient.

8. Summary

The German “Mantelverordnung” (Construction Materials Regulation) [1] was published in the *Federal Law Journal*. From August 1, 2023, this regulation is to be applied nationwide and, for the first time, regulates legally nationwide binding requirements for the recycling of mineral waste and its use in technical structures.

When using soils and construction MESC in earthworks, technical safety measures must be taken to ensure the responsible use of these materials from an environmental and water management point of view. The technical safety measures are to be designed in such a way that the seepage of soils and waste materials with MES Cand thus the possible discharge of pollutants is minimised to an acceptable level.

The Code of Practice (a law after 1 August 2023 in "Mantelverordnung") on Construction Methods for Technical Safety Measures when Using Soils and Construction materials with Environmentally Sensitive Contents in Earthworks (M TS E) presents a total of six different construction methods (A-E) for road embankments, which can also be applied to other earthworks. In principle, these can be divided into construction methods with barriers, construction methods with a low permeability body of soils and construction materials and core construction methods without barriers.

The M TS E describes different concepts of construction for the use of soils and construction/waste materials with environmentally relevant substances in earthworks. It differentiates between methods with and without barriers. The barriers can be weather-sensitive (typically with a clay/bentonite component) or weather-insensitive (polymeric barrier, such as a geomembrane). Construction methods without a barrier on the other hand can be built with or without drainage layers over the soils and construction/waste materials. Further, the code of practice recommends cover soil thicknesses to ensure long-term performance of the construction methods but does allow a reduction of cover soil thicknesses.

The M TS E guideline defines for geomembranes and geosynthetic clay liners specific product and durability requirements. However, as these are not completely listed and refer to other documents, this paper states further important product specific requirements for GCLs. A main focus is as well manufacturing and on-site quality control and assurance but does not specify in detail any requirements and leaves this to the designer.

Within the scope of a research project FE-Nr. 05.147/2007/CGB carried out by the Technical University of Munich, calculations were presented to investigate the effectiveness of different construction methods for the technical protection of soils and waste materials with environmentally sensitive contents in embankments in earthworks. A brief summary of the findings is presented and allows the conclusion that the combination of a barrier and a drainage layer over the barrier (method B) seems to show the best performance based on the numerical calculations with the FEFLOW flow simulator and it should be noted that the results showed that the actual conditions with the temporarily constant precipitation defined in the calculations are only reflected to a limited extent.

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