Rail Baltica

RBDG-MAN-015-0106

Design guidelines

# Railway substructure, Part 1 embankments and earthworks

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# 1. Introduction

This document describes the minimum requirements for designing the earthworks associated with the Rail Baltica railway line.

The design of the earthworks shall take into account following project constraints:

- design speed (249 km/h) of Rail Baltica railway line requires higher safety and durability requirements for passengers, systems and structures;
- wide range of temperature, frost, snow, etc.;
- presence of marshy areas and marshlands with permanently high water level;
- presence of thixotropic and compressible soils (including peat);
- groundwater level near the surface;
- potential countermeasures mitigating the potential climate-change-related issues.

This document describes:

- minimum requirements for earthworks for railway tracks and maintenance roads;
- design assumptions and the description of these assumptions which must be considered in project design, in calculating earthwork volumes and in proposing the cross section solutions;
- strategy regarding the reuse of on-site materials (Chapter 8).

# 2. References

## 2.1. Standards, norms, literature and guidelines

The main references related with the geotechnical and civil engineering aspects of the project and applicable in the European Community, are listed below (Ch. 2.2, 2.3 and 2.4).

## 2.2. Railway guidelines for Design

- [Text in this Chapter has been deleted intentionally]

## 2.3. Technical literature

Technical literature can be useful for designing the suitable solutions and these are for information.

- Atkinson and Farrar (1985) “Stress path tests to measure soil strength parameters for shallow landslips. Proc., 11th Int. Conf. on Soil Mech. and Found” Vol. 2 983-986
- Lord, Clayton, Mortimore (CIRIA C574, 2002) “Engineering in Chalk”
- Perry, Pedley, Brady (CIRIA C591, 2005) “Infrastructure cuttings – condition appraisal & remedial treatment”
- (CIRIA C731, 2013) “The international levee handbook”
- Lees (2012) “Obtaining parameters for geotechnical analysis”;
- Selig and Waters (1994) “Track Geotechnology and Substructure Management”
- Li, Hyslip, Sussmann and Chrismer (2015) “Railway Geotechnics”
- Indraratna, Salim and Rujikiatkmjorn (2018) “Advanced Rail Geotechnology – Ballasted Track”

## 2.4. Technical references

The mandatory technical references are:

- Regulation (EU) No 305/2011 (Construction Products Regulation)
- Regulation (EU) No 1299/2014 (Technical Specification of Interoperability)
- UIC 719R “Earthworks and track bed for railway lines”
- EN 13242 “Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction”
- EN 13285 “Unbound mixtures – Specifications”
- EN 13848-1 “Railway applications - Track geometry quality - Part 1: Characterization of track geometry”
- EN 1990 “Eurocode - Basis of structural design”

- EN 1991 “Eurocode 1 - Actions on structures”
- EN 1997 “Eurocode 7 - Geotechnical design”
- EN 1998 “Eurocode 8 - Design of structures for earthquake resistance”
- EN 14688-1 “Geotechnical investigation and testing - Identification and classification of soil - Part 1: Identification and description”
- EN 14688-2 “Geotechnical investigation and testing - Identification and classification of soil - Part 2: Principles for a classification”
- EN 13286-2 “Unbound and hydraulically bound mixtures - Part 2: Test methods for laboratory reference density and water content — Proctor compaction”
- EN 10223-8 “Steel wire and wire products for fencing and netting - Part 8: Welded mesh gabion products”
- EN 13250 “Geotextiles and geotextile-related products — Characteristics required for use in the construction of railways”
- EN 13251 “Geotextiles and geotextile-related products - Characteristics required for use in earthworks, foundations and retaining structures”
- EN 13252 “Geotextiles and geotextile-related products - Characteristics required for use in drainage systems”
- EN 13253 “Geotextiles and geotextile-related products - Characteristics required for use in erosion control works (coastal protection, bank revetments)”
- EN 13256 “Geotextiles and geotextile-related products - Characteristics required for use in the construction of tunnels and underground structures”
- EN 13383-1 “Armourstone – Part 1: Specification”
- EN 12699 “Execution of special geotechnical works – Displacement piles”
- EN 12715 “Execution of special geotechnical works – Grouting”
- EN 12716 “Execution of special geotechnical works – Jet grouting”
- EN 14199 “Execution of special geotechnical works – Micropiles”
- EN 14475 “Execution of special geotechnical works – Reinforced fill”
- EN 14490 “Execution of special geotechnical works – Soil nailing”
- EN 14679 “Execution of special geotechnical works – Deep mixing”
- EN 14731 “Execution of special geotechnical works – Ground treatment by deep vibration”
- EN 15237 “Execution of special geotechnical works – Vertical drainage”
- DIN 18134 “Determining the deformation and strength characteristics of soil by the plate loading test”

Please note that above mentioned references and standard may refer to other standards which are mandatory as well.

## 2.5. Supplementary Data

A detailed geotechnical investigation (preliminary and design investigations) shall be conducted to clarify the characteristics of the different geotechnical strata beneath the railway line and associated structures. Geotechnical investigation shall be done in accordance with Eurocode 7. Soils shall be classified according to EN ISO 14688-1, EN ISO 14688-2 and UIC 719R (soil quality classes).

# 3. Terminology

## 3.1. Stripping

Stripping is the operation by which the surface layer of the soil and primarily the topsoil is removed.

## 3.2. Cuttings

Cuttings refer to both the earthwork structure itself (i.e. railway line beneath the natural ground level) and the material excavated.

The earthwork structure is considered to be a cutting when the Point P (Zp) (described in Ch 3.16) is below ground level.

## 3.3. Embankments

Embankments are earthworks supporting a rail or road infrastructure raised above the natural ground level. Embankments can also be formed to deposit excavated materials which are not reused for constructing the railway or road structures.

Different terms related to the embankment height (height is measured between the top of the subballast layer and ground level) are as follows:

- low rise embankment, for which the height is:
  - ≤ 1,5 m, measured between the Point P (Zp) (described in Ch 3.16) and the ground level;
  - ≤ 1,2 m, measured between the top edge of the subballast layer and the ground level.
- level cuttings for which the height is measured between track bed thickness and ground level.
- high embankments for which the height is ≥ 12 m at the lowest point.
- medium height embankments include all other embankment heights.

Terms related to the embankment function:

- methodically compacted embankments are designed to support the railway tracks or roadway. These include the whole embankment in addition to the upper part.

- technical blocks are the embankments in the transition area adjacent to structures (e.g. bridges, hydraulic structures, etc.).

All other embankments are classed as “ordinary” (e.g. berms, depots).

## 3.4. Embankments in damp areas

Embankments located in hydromorphic areas (areas where the soil is saturated with water for at least part of the year). The design of embankments in those areas is aimed at preventing the capillary rise of water into the embankment to an extent which can cause structural disturbances (e.g. low bearing capacity, frost heave, swelling, etc.) within the embankment.

## 3.5. Embankments in marshlands

Embankments built in marshland areas must meet the characteristics and requirements for “Embankments in damp areas” (Ch. 3.4) and “Embankments on compressible soils” (Ch. 3.11).

## 3.6. Embankments in flood risk areas

Embankments in flood risk areas can temporarily be flooded.

## 3.7. Embankments built underwater

Embankments that are constructed below water level or are permanently flooded.

## 3.8. Reinforced embankments

Embankment earthworks made up of a solid embankment block, stabilised by means of reinforcement (e.g. inclusions, aggregate columns, bracings, coverings, facings, etc.) specific to each procedure.

## 3.9. Supporting soil

The ground on which earthwork rests. A distinction is made between stable and unstable supporting soil (e.g. compressible, collapsible, liquefying, disturbed, expansive, etc.). These factors shall be taken into consideration when designing the earthworks.

## 3.10. Swelling soils

Soils whose volume may increase for several reasons and therefore may lead to uplift of the rail track if these soils are used in the main body of an embankment, in the track structure or in the cuttings (if they are present under the finished earthworks).

## 3.11. Compressible soils

Soils whose intrinsic properties lead to deformations under static and dynamic loads, i.e. settlement or reversible deformation can occur, caused by rail traffic, which is detrimental to earthworks.

## 3.12. Riprap structures

Protective structures consisting of rocky blocks (e.g. armourstone produced according to EN 13383-1) placed at the base of banks, sloped sections and river banks to protect them from erosion caused by water.

## 3.13. Gabions

Structures constructed from rocks bound together into blocks by a parallelepiped-shaped metal latticed cage.

Gabions can be used to protect banks, as a low retaining structures, as a protection against rockfall and as a sound barrier.

## 3.14. Drainage layers and filter layers

Layers that ensure the drainage and, if necessary, the stability of banks that are affected by the groundwater level. A distinction is made between layers whose sole function is drainage (i.e. drainage layers), and layers that simultaneously provide a draining and filtering function (i.e. filter layers).

## 3.15. Protecting layers

Structures protecting the surface of the banks.

## 3.16. Point P (Zp)

The Point P corresponds to the top of the subballast layer at the centreline of the project.

## 3.17. Subballast layer

The subballast layer is a part of the track bed structure and it is constructed from a layer of permeable, coarse-grained and wellgraded material that is insensitive to water and frost. Subballast layer is constructed between the prepared subgrade and the ballast layer. It may include a geosynthetic layer at the bottom of the layer, if necessary.

## 3.18. Prepared subgrade

Prepared subgrade is a more or less complex track bed layer, which enables the unpredictable and scattered properties of the backfill material or existing ground to adapt to the mechanical, geometric, hydraulic and thermal properties taken as a basis for the design of the earthworks. The layer is constructed of permeable and well graded material that is insensitive to water and frost. Prepared subgrade layer is constructed between subballast layer and embankment.

## 3.19. Slope

xH/yV: x for Horizontal and y for Vertical

## 3.20. Frost susceptibility of a soil

Frost susceptible soils tend to cause frost heave when soil is freezing and loose bearing capacity when soil is thawing. In order to cause frost heave, following criteria must exist simultaneously:

- Soil is frost susceptible;
- Temperature in the soil is low enough to cause freezing;
- Free moisture is available to cause formation of ice lenses.

Since frost heaving is not allowed to occur on Rail Baltica railway lines, the frost susceptibility of subgrade, embankment and track bed materials must be taken into account. Many different soil frost susceptibility criteria exist, e.g. direct measurements while freezing the soil or gradation-based limits (incl. silt and clay particles). Please see UIC 719R for more information about suitable soil frost susceptibility criteria.

*NOTE: Suitable frost susceptibility criteria, which takes into account the UIC 719R recommendations, are described in article "Determination of frost-susceptibility of soils" (1989, E. Slunga, S. Saarelainen).*

## 3.21. Frost resistance

Frost resistance is a property describing aggregates' resistance to freezing and thawing environmental conditions (freeze thaw cycles). An aggregate is considered to be frost resistant if it fulfils appropriate frost resistance category based on EN 1367-1. Appropriate frost resistance category shall be defined in the documents related to the application of the construction materials, taking into account the conditions in place of use.

# 4. General requirements

Earthworks shall be designed in accordance with following standards:

- EN 1990 Eurocode;
- EN 1991 Eurocode 1;
- EN 1997 Eurocode 7.

Please note that above mentioned standards refer to other standards which must be taken into account as well.

Earthworks shall be designed, taking into account following:

- Geotechnical Category is 2 or 3, as described in EN 1997-1;
- Vertical loads are based on Load Model 71 (LM 71) according to EN 1991-2 Ch. 6.3.2 or Ch. 6.3.6, if applicable;
- LM 71 characteristic values must be multiplied with factor $\alpha \geq 1{,}1$. For retaining structures:
    - on mixed traffic sections factor α = 1,46 must be selected
    - on passengers only and light freight sections factor α = 1,46 is recommended
    - when connected with a different structure such as viaduct, bridge etc., the retaining structure shall use the same alpha factor as the connected structure (see RBDG-MAN-017)
- Dynamic factor $\Phi$ shall be selected based on EN 1991-2 Ch. 6.4.5.2, but not less than (or equal to) 1,25.

Stability shall be verified both for embankments and cuttings, taking into account short-term and long-term design situations. Detailed specifications of design situations shall be described in the proposed design.

For geotechnical design, load situation according to TSI INF 4.2.7.2 must be applied.

## 4.1. Maintenance, reliability and durability of structures

Earthworks, including cuttings, embankments and railway track formation, shall be designed and constructed for a design working life of 100 years due to the impact that any repairs would have on railway operations. No substantial reinvestment has been earmarked for earthworks or infrastructures within this period.

**This long design working life shall be taken into account when choosing appropriate technical solutions.**

Certain elements associated with different structures, e.g. drainage, vegetation, or gravel traps will still require routine maintenance. Therefore, the specific maintenance activities required to ensure the reliability and durability of the technical solutions, proposed for the entire life cycle of the railway system, shall be clearly stated.

## 4.2. Geotechnical investigations, on-site tests, stability calculations and safety coefficients

The geometry of earthworks, including cuttings and embankments, shall be engineered and justified by static and seismic stability calculations, short-time and long-time settlements calculation, punching failure calculation by means of recognised methods that are traditionally used in soil mechanics and geotechnical engineering. Geotechnical design shall be done in accordance with appropriate Eurocodes.

The calculation method for stability shall be adapted to the type of failure:

- Bishop Method or equivalent for circular failures;
- Disturbance Method or equivalent for non-circular failures.

The expert responsible for choosing geotechnical input and parameters shall comply with the following guidelines and principles in conducting stability calculations in order to ensure the reliability of the calculation codes:

**Geotechnical parameters shall be defined keeping in mind to choose safety values based on:**

- *In situ* data extracted from geotechnical investigations and laboratory tests made for the project;
- geological and geotechnical literature;
- feedback experience on earthworks carried out in the same geological units;
- perfect awareness of the possible variability of the geological model.

A representative number of tests shall be carried out on undisturbed soil samples for the design.

**Some cases require special calculations:**

- For embankments:
  - Stability shall be verified for static and seismic situation.
  - Punching failure shall be verified.
  - Settlement shall be calculated.
  - Specific requirements:

        - On compressible soils, a high stability coefficient (Ultimate Stress Level) for the short-term stability calculations (in the embankment construction phase) shall be used. This is the most critical phase in the structure's life for both punching and circular failure.
        - The undrained cohesion values measured with scissometer (Vane Shear Test) will be modified using a factor that takes into account the type and state of the soil.
        - For embankment materials zero cohesion shall be used as an input due to the risk of cracking caused by settlements.
- For cuttings:
    - Stability shall be verified for static and seismic situation.
    - Specific requirements:
        - For the slopes of cuttings excavated into loose soils, it is generally the long-term phase that is the most critical in terms of stability, therefore the quality and characteristics of the drained materials shall be defined.
        - For the slopes of rock cuts, no blocks, rocks or other debris may be allowed to reach the railway infrastructure in terms of material sliding directly onto or across the rail line over the lifetime of the structure.
- Partial coefficient and Security factor
    - Static stability can be calculated by two ways:
        - With no partial coefficient for geotechnical parameters of the soil and searching a security factor of 1.5 minimum.
        - With partial coefficient for geotechnical parameters of the soil (design approach 2 and 3 according to Eurocode 7) and searching a security factor of 1 minimum.
    - Seismic stability shall be calculated with partial coefficient and by using earthquake characteristics based on geological stratigraphy and level of seismic risk. These parameters are defined in Eurocode 8.

## 4.3. Classification of soils for reusing in embankment fill and determination of the class of soil supporting the prepared subgrade

The UIC 719R defines a qualitative approach for classifying soils, depending on their geotechnical classifications. According to UIC 719R, soils are devided into **four** different soil quality classes:

- QS0: « Unsuitable » soils which do not form a suitable subgrade and therefore require improvement (replacement to a certain depth with better quality soil, stabilization with binding agents, use of geotextiles, reinforcement with piles, etc.). For this reason, these soils are not considered when dimensioning the track bed layers.

- QS1: « Poor » soils which are acceptable in their natural condition subject to adequate drainage being provided and maintained in good order. These soils could be considered for upgrading by means of the appropriate treatment (e.g. stabilization binding agents).

- QS2: « Average » soils.

- QS3: « Good » soils.

QS0 soils shall be stabilized or put in definitive deposit. Feasibility for using different stabilization methods (e.g. chemical or mechanical stabilization) for each soil class shall be performed during the design phase.

For more information regarding qualitative soil classification, please see UIC 719R Ch. 1.3.

# 5. Construction in areas of standard design

## 5.1. Topsoil Stripping

The aims of topsoil stripping is to:

- retrieve topsoil for protecting the banks or to develop the area around the track bed (vegetation);
- remove material that is not suitable for reuse;
- identify and select materials, according to their characteristics, for reusing;
- remove the potential risk that the supporting soil may cause settlements.

Stripping is obligatory on slopes and underneath all level embankments. However, it is not technically necessary underneath the ordinary embankments and particularly in non-trafficable areas.

For every earthwork to be constructed, the thickness of the topsoil stripping shall be established based on investigation and analysis of its characteristics.

Understanding the characteristics and the thickness of the topsoil will help to optimise the cost of the construction, estimate topsoil stripping volumes and manage the excavated material based on its nature and intended future use.

## 5.2. Cuttings

### 5.2.1. Geometry

The width at the base of the earthwork cuttings shall be determined based on the requirements of the railway installations and design:

- the thicknesses of the track bed  layers (prepared subgrade, subballast, ballast);
- the nature and position of the longitudinal drainage;
- the maintenance paths;
- gravel and stone traps;
- any other maintenance and accessibility requirements.

An evaluation of the cuttings, their slope stability, slope definition and overall geometry is based jointly on geotechnical investigations and stability calculations. These stability calculations shall be done and the results shall be verifiable and satisfactory.

Stability calculations shall take into account at least the following:

- geotechnical characteristics of the subgrade soil and the construction materials used;

- geometry of the structure;
- site conditions (topography, hydrology and hydrogeology, weather conditions, frost, etc.);
- possible presence of any natural risks identified (landslides, rockfalls, collapses, seismic hazards, etc.).

For visual identity and geometry of the Cuttings please refer to RBDG-MAN-031F.

### 5.2.2. Hydrogeological Classification

The piezometric level is deduced from piezometric measurements and hydrogeological understanding of the site, taking into account the seasonal variations. It is necessary to ensure that the measured piezometric level is representative, especially in the case of less permeable soil, for which open piezometers are not appropriate.

Cuttings are defined, from a hydrogeological aspect, according to the position of the groundwater in relation to point P (Zp):

- cuttings are considered “dry” if:
  - there is no water table;
  - there is a regular water table, but estimated highest water level (HWL) is at least 0.50m below the bottom of the prepared subgrade layer, or;
  - there is an inconsistent water table (perched water table);
- cuttings are considered “damp” in all other situations.

### 5.2.3. Specific requirements

The slopes of the cuttings shall be stable. No slippage is permissible, and the trajectory of instable material or rock shall not cross the railway clearance or reach the railway infrastructure.

For the cuttings, following design and construction requirements shall be considered as a minimum:

- guarantee the stability of the structures against slippage;
- obtain the bearing capacity at the foundation level of the earthworks;
- erosion control of the side slopes;
- water control in the structure (transport of surface water, possible circulation of water inside the cutting, deleterious effects of variable moisture content).

The slopes of the cuttings shall be designed and engineered to ensure the functionality, stability and sustainability of the structure.

The foundation level of the earthwork improvements concerning cuttings shall be drained.

The drainage system shall therefore be designed so that the prepared subgrade will not be damaged by the capillary rise of water and the groundwater table level shall be at least at 0.50m below the prepared subgrade in order to ensure the long-term durability of the track bed.

The clause above also concerns level embankments and cuttings.

The means available for drainage in the slopes of cuttings shall be examined with care in terms of their design and construction in order to mitigate the risk of destabilisation that could result from their malfunction (erosion of the embankments or groundwater infiltration into the cutting).

All drainage measures to be adopted in the final design shall be specified.

If the excavated surface of a cutting is going to support prepared subgrade directly, the excavated surface of a cutting shall have same requirements for compaction degree of $D_{pr}$ and $E_{V2}$ as embankment (Ch. 5.3):

- Compaction degree shall be ≥ 97% (EN 13286-2 standard Proctor).
- $E_{V2}$ measured in accordance with DIN 18134 shall be:
    - $E_{V2} \geq 45$ MPa for fine soils;
    - $E_{V2} \geq 60$ MPa for sandy of gravelly soils;
    - $E_{V2} \geq 80$ MPa for treated soils.

## 5.3. Embankments

### 5.3.1. Geometry

Geometrically, the width of the upper part of the embankments shall take into account:

- the characteristics of the installations;
- specific project features (e.g. landscape changes, noise barriers, detailed maintenance requirements);
- the thicknesses of the track bed layers (e.g. prepared subgrade, subballast, ballast);
- estimation of primary and secondary (creep) settlement during the construction and operational phases.

An evaluation of the cuttings, their slope stability, slope definition and overall geometry is based jointly on geotechnical investigations and stability calculations.

These stability calculations shall be undertaken, and the results shall be verifiable and satisfactory.

Stability calculations shall take into account the following at the very least:

- geotechnical characteristics of the subgrade soil and the construction materials used;
- geometry of the structure;
- site conditions (e.g. topography, hydrogeology, climatic conditions);
- possible presence of identified natural risks (e.g. slides, falls, subsidence, seismic activity).

For visual identity and geometry of the Embankments please refer to RBDG-MAN-031F.

## 5.3.2. Embankment requirements

The slopes of cut embankments shall be designed and engineered to ensure the functionality, stability and sustainability of the structure.

The stability calculations and design of the embankments shall allow for possible changes in surface materials with a particular focus on freeze-thaw deterioration or erosion from the impact of rain and wind (integration of surface protection systems).

The following design and construction requirements for embankments shall be applied:

- guarantee the stability of the structures against slippage;
- guarantee of the absence of harmful deformations after the completion of the earthwork improvements (settlement, cracks and swelling);
- guarantee of the stability of the soils supporting the structures including acoustic protection;
- erosion control of embankment slopes;
- control of the hydraulic environment (surface water, possible circulation of water within the embankment, deleterious effects of variable moisture content).

Additional slope protection, special drainage or other reinforcement systems (draining trenches, slope drains) may need to be designed and engineered for the embankment and integrated into the structures to satisfy the stability requirements. These systems shall have the same design working life as for the main structure and shall be easily maintained and cleaned.

A specific document justifying the stability of high embankments, including the slopes and balance of the structure, regarding the slip factor, is required. This document shall also contain details of the constraints internal to the embankment due to its weight, scale and settlement.

Minimum embankment compaction requirements are following:

- $D_{pr} \geq 97\%$ (EN 13286-2 standard Proctor) shall be achieved for methodically compacted embankments;
- $D_{pr} \geq 97\%$ (EN 13286-2 standard Proctor) for rail bridge;
- $D_{pr} \geq 97\%$ (EN 13286-2 standard Proctor) for road bridge density objectives for technical blocks;
- Ordinary embankments shall be constructed in the same way as methodically compacted embankments when they are adjacent to the latter in any capacity. This includes stability and compaction level requirements. Compaction objectives for ordinary embankments are described in the the proposed technical design if it is necessary for long-term stability.

$E_{V2}$ measured in accordance with DIN 18134 shall be:

- $E_{V2} \geq 45$ MPa for fine materials;
- $E_{V2} \geq 60$ MPa for sandy or gravelly materials;
- $E_{V2} \geq 80$ MPa for treated materials.

The geometry and construction of the embankments shall accommodate possible changes in the slopes with a particular focus on freeze-thaw deterioration or erosion from the impact of rain and wind, swelling and damage to other materials.

Special protection shall be adopted for the embankments in areas where burrowing animals are likely to be encountered.

Level embankments shall also be designed and engineered to accommodate the drainage requirements of the Upper Section of Earthwork defined above. If these conditions can't be met, particularly without a drainage outlet, the embankment will have to consist of "flood zone" materials as defined below.

## 5.4. Cutting embankment transition zones

These are the transition areas between cuttings and embankments. These zones present different material characteristics in the cutting/embankment sections and may therefore also have different rail track structures (track bed layers and sub-layers).

Cutting-embankment transition zones shall specifically be able to guarantee:

- the continuity of the longitudinal bearing capacity of the supporting soil;
- the continuity of the longitudinal bearing capacity of the railway track structures;
- the absence of absolute and differential settlement of the railway track in operation;
- the absence of water movement from the cutting to the embankment through the supporting soil and track structures. For this purpose, a transverse drainage trench is necessary when the ramps are important in the direction "cut to embankment" (between 20 and 35 $^{0}/_{00}$).

The natural ground shall be stepped to enable construction of the embankment in cases of embankments with a natural slope greater than 15 %.

## 5.5. Compressible soil areas

### 5.5.1. Compressible soil area requirements

For ballasted tracks, the maximum settlement authorized is 10 centimetres at an annual rate of less than 1cm/year over 25 years. The start of measurement shall be the turnover date upon successful completion of the subballast layer.

In the case of slab track, a specific study shall be performed into maximal permissible settlement.

Differential settlement shall be limited to the values established in European standard EN 13848-1 for maintaining the track geometry with longitudinal levelling at a difference of less than 3 mm measured over 15 m and less than 8 mm measured over 30 m, and for the cant of the track (isolated defect in the relative levels of the two stretches of rails of less than 3 mm measured over 3 m).

All settlement and stability calculations shall take into account railway operating loads including static loading due to the superstructure and rolling stock.

Adjacent to bridges, the requirements for permissible residual settlement and the consolidation period may be more stringent to ensure the absence of differential settlement between the Technical Blocks (Ch. 5.7) and the bridge. For the technical blocks, the maximum settlement is 4 centimetres at an annual rate of less than 1cm/year over 25 years.

These items shall be constructed to be compatible with the design of the bridge foundations, the program and phasing of the earthworks.

The potential impact of settlement on adjacent structures shall also be taken into account.

It should be noted that for disturbed supporting soil, i.e. soil whose characteristics may have been modified between project scoping and construction (for example following archaeological excavation or preparatory work, etc.), the requirements for earthworks on compressible soils shall apply.

The thixotropic soils are specific compressible soils which can be liquefiable. These soils shall be studied with special attention with specific geotechnical investigations.

### 5.5.2. Unacceptable alternatives for treating compressible areas

All techniques and technical solutions that do not allow verification of compliance with respect to design and engineering along with reliable settlement estimations during the operational phase are prohibited. During the designing process, the geotechnical engineer must propose constructive arrangements to obtain the results mentioned in the design guidelines:

- 10 cm settlement maximum in 25 years;
- 1 cm/year maximum.

## 5.6. Reinforced earthwork improvements

The proposed reinforcement processes shall be justified economically and technically with respect to railway safety and durability.

This justification shall include following points:

- internal stability of the reinforced structure and overall stability of the structure on its own and with dynamic loads from rail operations as required;
- prediction of the inherent behaviour of the reinforced structure under operational loads including deformation;
- allowance for the technical and economic aspects, including traffic impact, associated with maintenance requirements of these structures (vegetation, painting, etc.);
- ensure that the proposed solution, including component resistance, dimensions and durability, provides a design life of at least 100 years after taking into account site conditions (attack by water and soil, fatigue due to railway stresses, electrolytic corrosion due to railway electrification, etc.);
- define the equipment used for periodical checks into the integrity of the reinforcing elements along with a proposed inspection schedule complete with warning and/or investigation criteria;
- define the repair processes required to correct unforeseen behavioural defects in the reinforcement without dismantling the structure, along with their potential impact (increased width maintenance tracks, duration of the repairs, possible consequences on railway operations).

The solution proposed for these reinforced structures shall also accommodate special risks (e.g. areas exposed to the risk of fire or vandalism, other environmental impacts, etc.).

The above justifications shall also be provided for the anchor rods passing beneath the railway structure.

# 5.7. Technical blocks

## 5.7.1. Technical block overview

### 5.7.1.1. *Function of a technical block*

The connection between the embankments and integrated structures, such as bridges in the project shall be made up of a specific embankment structure (except in special cases, e.g. diaphragm walls, steel sheet piles), adjacent to the structure, this being referred to as a "Technical Block".

Technical Blocks are necessary to ensure a smooth transition between the hard surfaces of the integrated structures (e.g. concrete bridges) and their associated embankments with lower stiffness. The design and construction quality of these technical blocks shall comply with more stringent requirements than standard sections and shall prohibit any settlements (including differential settlement) between the structures and its associated embankments.

Technical blocks shall also mitigate damaging hydraulic pressure build-up behind the abutments of the structures.

For rail bridges (structure supporting the railwaytrack), the construction of a technical block is essential to ensure the safety of rail traffic, the comfort of passengers and the sustainability of the track bed.

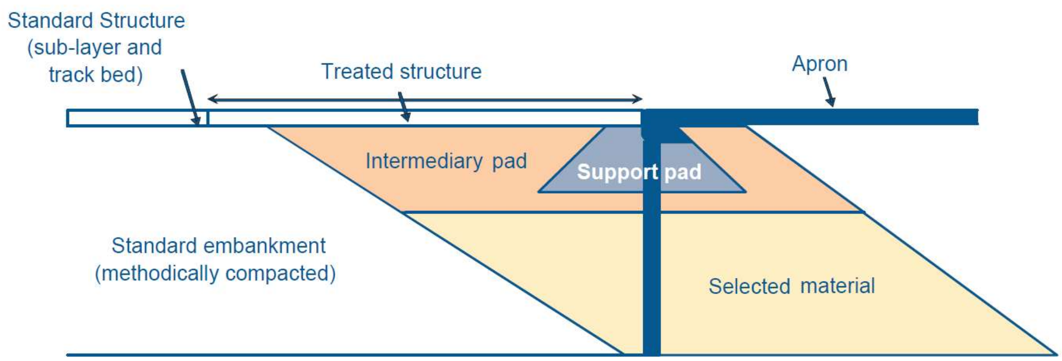
Technical blocks shall be constructed only on stable soils, avoiding risk of unacceptable settlements after completion of the construction process.

### 5.7.1.2. *Structure and geometry of the technical blocks for rail bridges*

The design, positioning, geometry, method of construction and the materials used in the technical blocks for rail bridges is, as a minimum, dependening on the following factors:

- the type and geometry of the bridge;
- the height of the approach railway embankment;
- the thickness between the extrados of the structure and the top of the railway track bed or road ("overlap thickness");
- the degree of skew of the bridge (the angle between the railway centre line and the track). The extension of the 'intermediary pad' at the junction with the approach embankment (see detailed drawing below) shall always be perpendicular with the tracks even in cases where the skew can be large;
- the phasing of the embankments (completion of the embankments before or after the bridge structure).

The various parts of a technical block are described in the drawing below:




1. TECHNICAL BLOCK EXAMPLE

This schematic diagram shows the various parts of a technical block (general case of a simply-supported rail bridge, the technical block of which is constructed after the approach embankment as indicated by the slope between the block itself and the standard embankment). For more information regarding technical block design, please see UIC 719R Ch 2.3.5.

The support pad is constructed, using hydraulically bound mixture, produced according to appropriate product specification, for example EN 14227-1.

In these cases, technical solutions shall be proposed in relation to the technical blocks, specifying the criteria adopted as follows:

- the overlap thicknesses according to the type of infrastructure and the extent to which they are embedded;
- the constituent materials detailing their durability, bearing capacity and resistance characteristics.

In particular, the aggregates shall meet the following specifications:

- produced according to EN 13242 and/or EN 13285;
- maximum aggregate size D shall be ≤ 90 mm;
- contain no detrimental elements which could damage concrete structures;
- be compatible with the projected angle of slope.
- if needed, treatable with cement (EN 13242)

These specifications are also required for rail bridge transition zone:

- On a length of 20 m, the subballast and subgrade are to consist of a treated sandy gravel mixture on a thickness of 0.8m.
- On a length of 5m at least, the embankment consists of intermediate solid blocks. At the exit of the bridge, on a length of 1m at least, the embankment consists of treated materials.

For the technical blocks of road bridges (bridge supporting a road), the requirements and/or recommendations of the National Road Administrations shall be taken into account.

During the construction phase, the passage of vehicles over the underlying structural slabs will not be permitted unless there is protective layer on top of the structural slabs with a thickness of at least 0.80 m plus the assumed depth of the tracks.

#### 5.7.1.3. *Technical block "treated structure" section*

This is necessary for non-buried structures having no sub-layer or track bed on the bridge deck: there is a direct transition between the standard embankment and bridge deck, making it a critical point with an even greater vertical elasticity transition in the technical block between the approach embankment and the bridge itself.

The track bed layers and sub-layer covering the technical block on either side of the structure may be replaced by a subballast layer, a treated sandy gravel mixture, compacted to $D_{pr}$ = 103% (EN 13286-2 standard Proctor) and at a thickness identical to the track bed/sub-layer (or minimum thickness of the frost penetration depth) of the adjacent earthwork structure.

This treated zone will cover the entire length of the technical block in the longitudinal direction with a minimum length of 20 m and the whole width of the embankment (excl. buried cable conduits).

In the event of excess width to accommodate noise barriers, the treated structure is to be limited to the width between the foundation blocks of the barrier. In the case of a collector drain, the treated structure is limited to the inner vertical side of the drainage collector excavation.

#### 5.7.1.4. *Technical block - various*

The geometry of the blocks and portal frame structures is independent, regarding the construction phase, between the approach embankment and the structure.

In case the embankment is constructed before the structure, enough space shall be designed and specified between the end point of the embankment and the base of the technical block to be constructed. This will enable the final link between the embankment and the technical block to be compatible with the earthwork methods used.

## 5.8. Embankment in damp areas

In addition to the specific requirements for all embankments (Ch. 5.3), the embankments in damp areas are subject to special attention regarding the following aspects:

- the stability of the embankment resting on an area prone to the capillary rise of water;
- the capillary rise of water in the embankment shall not reach above 0.75 m measured below the bottom of the prepared subgrade layer in order to maintain the required bearing capacity of the track bed layers.

The dimensions and the design of the embankments shall also take into account:

- the possible level of the capillary rise of water, in relation to the natural ground and the surface of the base layer;
- the nature and intrinsic properties of the supporting soil;
- frost action.

Materials in damp areas shall be equivalent in bearing capacity, sustainability and other characteristics to the following:

- granular materials insensitive to water and washout of infill material and to frost;

- maximum aggregate size D ≤ 630 mm;
- treated materials of sufficient post-treatment quality.

Deep lateral trenches may be designed and constructed at the base of the embankment if the saturated area can be drained, to dry out the subgrade supporting the embankment and to control the risks associated with the capillary rise of water.

A layer of granular materials, with a thickness of ≥ 0,3 m, acting as an anti-capillary layer can be designed to mitigate the issues related with capillary rise of water.. Additionally, a composite geosynthetic (barrier and drainage) blocking the capillary rise into the embankment or layers above, can be considered for that purpose.

**Embankments in damp areas constructed with materials treated with hydraulic binders on compressible supporting soils are forbidden.**

## 5.9. Embankment in flood zones

Embankment materials in flood zones shall be insensitive to water and also unaffected by water circulation inside and outside of the embankment in order to mitigate the risk of washout of infill material and piping. These materials are called “flood zone materials”.

The height of the submerged section is equal to the “Highest Water Level” (HWL), determined by a specific hydraulic study with a probability of once in 100 years and shall be designed with a safety margin of HWL + 0.5 m.

The overall stability and durability of the embankment and track bed layers shall be demonstrated in the event of flooding (e.g. retaining bearing capacity, absence of swelling, settlement, or risk of subsidence).

Embankments in flood zones shall be designed and constructed to meet the following criteria:

- resistance to external erosion (e.g. erosion of the slopes);
- resistance to internal erosion (e.g. washout of infill material, piping);
- resistance to fast drainage.

These resistances shall be determined by calculation(s), including the necessity to use Rockfill on the slopes for erosion protection.

The embankment design (stability calculations, verification of resistance) shall take into account:

- the HWL value;
- the frequency and duration of floods (risk analysis);
- the speed of run-off and its direction in relation to the embankment;
- wave action.

Settlement due to the weight of the embankment itself shall be taken into account.

Embankments in flood zones are to be treated as methodically compacted embankments.

Flood zone materials shall be equivalent in bearing capacity, sustainability and other characteristics to the following:

- granular materials insensitive to water and washout of infill material and to frost;
- maximum aggregate size D ≤ 630 mm;
- fines (<0,063 mm) content shall be ≤ 5%;
- treated materials of sufficient post-treatment quality.

**Flood zone embankments in materials treated with cement are not allowed on compressible soils due to the risk of induced cracking.**

## 5.10. Embankment in marchland areas

Embankment materials in marchland zones shall be insensitive to water and stay unaffected by water circulation inside and outside of the embankment in order to mitigate the risk of erosion, washout of infill material and piping ( "flood zone" materials).

The height of the submerged section is equal to the "Highest Water Level" (HWL), determined by a specific hydraulic study with a probability of once in 100 years and shall be designed with a safety margin of HWL + 0.5m.

The overall stability and durability of the embankment and subballast layer shall be demonstrated in the event of flooding (e.g. retaining bearing capacity, absence of swelling, settlement, or risk of subsidence).

Under the embankment, unsuitable materials shall be replaced.

Filtering and/or separating layers or geosynthetics are systematically placed between the natural soil and the embankment material to avoid contamination of the embankment and subsoil with fine particles.

Embankments in marchland zones shall be designed and constructed to meet the following criteria:

- resistance to external erosion (e.g. erosion of the slopes);
- resistance to internal erosion (e.g. washout of infill material, piping);
- resistance to fast drainage.

The embankment design (stability calculations, verification of resistance) shall take into account:

- the HWL value;
- the frequency and duration of floods (risk analysis);
- the speed of run-off and its direction in relation to the embankment.

Settlement due to the weight of the embankment itself shall be taken into account.

Embankments in marshland zones shall be designed, considering both requirements for embankments in damp areas and for embankments on compressible soils.

The geotechnical investigation in these areas must be cautious with the hydrogeological conditions and define if specific requirements need to be considered (i.e. draining the base in case of water sources capitation, gradual surcharge for construction, etc.).

Embankments in marchland zones are to be treated as methodically compacted embankments.

Flood zone materials shall be equivalent in bearing capacity, sustainability and other characteristics to the following:

- granular materials insensitive to water and washout of infill material and to frost
- maximum aggregate size D ≤ 630 mm;
- Fines (<0,063 mm) content shall be ≤ 5%;

**In marchland zones the usage of hydraulically bound materials are not allowed to be used in embankments due to the risk of induced cracking.**

## 5.11. Embankment built underwater

In addition to the specific requirements for all embankments (5.3), the embankments built underwater shall also fulfil the following other requirements:

- the general stability of the works;
- the insensitivity of the embankment materials to water;
- the material's property to "auto-compact" by means of a suitably adapted particle size distribution;
- resistance to liquefaction (particularly vis-à-vis vibrations);
- the absence of damaging deformations, such as settlements, expansion, cracking, etc.;
- the achievement and maintenance of the required bearing capacity on the surface of the embankment, prepared subgrade and subballast layer;
- resistance to external erosion;
- resistance to rapid draining;
- a guaranteed defence against "piping" if necessary.

The embankment design shall take into account:

- the HWL in relation to the natural ground and the surface of the base layer;
- the presence of water - frequency and duration;
- the speed of any run-off and its direction in relation to the embankment;
- wave action;
- the nature of the supporting soil;
- potential frost (only for the section of the embankment close to the surface).

Point P shall be at least 1.50 m above the HWL.

These embankments shall be built from granular materials which meet the following criteria:

- Maximum aggregate size D ≤ 630 mm;
- less than 10% passes through a 5 mm sieve;
- more than 60% passes through a 50 mm sieve;
- fines (<0,063 mm) content shall be ≤ 5%;
- frost resistant for the surface sections of the work.

**Treated materials are not allowed for the construction of embankments built underwater.**

## 5.12. Swelling supporting soils

Every type of swelling shall be be taken into account - swelling due to water absorption, through draining, through contact with the air or bacteria (paper shale), through a chemical reaction of certain components (sulphates, nitrates, etc.) usually after treatment or contact with treated soil (lime or hydraulic binders), or even through the creation of new mineral types (ettringite, etc.).

Soil swelling in the subgrade layers in the earthwork infrastructure of a railway is a major problem because, unlike settlement that can (to some extent) be offset by increasing the thickness of the ballast, swelling (even minor) cannot be offset by any regular servicing or maintenance operations.

Soil swelling on railway lines shall be limited or avoided altogether and can only be tolerated in specific and justifiable cases on the condition that this swelling is limited to very small amplitudes that are compatible with the durability and maintenance of the equipment and remain within the geometric tolerances of the track (the same tolerances apply as for settlement in compressible areas) at rates of swelling less than 1 cm/year.

All necessary studies shall be undertaken, and all necessary measures implemented to avoid the risk of subgrade soil swelling.

The results of these studies may lead to the implementation of specific provisions (catenary masts, etc.). The areas where the presence of soils subject to swelling may possibly be acceptable are, generally limited to “straight track” without points.

An analysis of swelling will only be made in cases where this cannot be avoided by construction measures (natural swelling and areas where soil replacement or drainage are not possible).

Any analyses of swelling will focus on assessing the risk of differential and unpredictable movements in relation to the project characteristics (proximity to structures, presence of points, etc.). Railway loads (static loads exerted by the superstructure and rolling stock) shall be taken into account.

**The use of any technique that may provoke swelling (soil treatments, etc.) is automatically prohibited, regardless of any studies that may be undertaken to justify it.**

## 5.13. Underground cavity areas

These are areas where the land may be subject to underground cavities from many sources, including: both natural (active or fossil karsts) or anthropogenic (mines, quarries, buried structures, etc.), existing open or filled cavities, or other areas with the potential to develop underground cavities (soils susceptible to dissolution).

The railway line track formation and any additional formations shall not be exposed to the risk of collapse for the design life of the structure. All risk areas that are identified by studies or during the construction phase shall be subject to specific mitigation measures.

All studies, investigations and analyses necessary to avoid the risk of collapse due to underground cavities shall be undertaken.

The procedure to search for natural and anthropogenic cavities shall be carried out with particular care. During the study, design, engineering and construction phases, investigations shall be adapted to the type of cavities considered (size, depth, vacuums or filled space, etc.) and to the type of land (nature, types of strata, water content, etc.).

Any environmental impact caused by remediation work shall be evaluated and taken into account when mitigating potential underground cavity risks.

To the greatest extent possible, cavities shall be solidly filled. Although, the risk of modifying the movement of ground water shall also be taken into account.

Further, infiltrations of surface water into areas that may contain underground cavities of any kind shall be eliminated or mitigated to the greatest possible extent.

Studies conducted in the design phase shall be supplemented by additional surveys undertaken in the construction phase.

The design phase study should allow for the identification of cavity types and for them to be prioritised by area through a documentary approach, including geology, aerial photos, administrative and local investigations, karstification and/or caving studies, historical archives, etc.

This documentary research will be supplemented (in the areas of interest and accessibility) by suitably adapted geophysical surveys.

Additional geophysical and geotechnical surveys will be made during the construction phase. These should be adapted as the earthwork improvements and infrastructure progress and will depend on the discovery of actual cavities or indications of cavities (whatever the original “risk” or “non- risk” area classification); these surveys may also be needed in areas identified as being at risk during the preliminary study but where additional surveys were neither technically feasible nor practical prior to the start of Earthworks construction.

The scheduling of additional, foreseeable surveys should be based on the earthworks programme.

In the construction phase, regardless of the results of studies, surveys, or remediation work carried out, an inspection of the earthwork foundation level will be made by a qualified geologist at all suspected or known areas where there is a risk of underground cavities. This inspection will determine the absence or presence of any residual evidence of cavities before embankments are constructed or track structures laid (in cuttings).

Locally, surveillance methods may be needed during the operational phase even after remediation work has been carried out. The areas concerned shall be covered by a document that clearly presents the monitoring methods, their frequency and alert protocols.

On completion of all remediation works, the areas treated will be subject to specific surveys in order to ensure the quality of the remediation measures and to quantify any residual risk.

## 5.14. Seismic areas

In areas where there is the risk of earthquakes, the stability of earthwork improvements and the corresponding infrastructure shall be submitted to an additional pseudo-static analysis, taking account of the application of lateral acceleration $\alpha max$ to be defined in accordance with the applicable regulations of the Authority(ies) with jurisdiction in this field. For this verification, a safety factor of at least 1 is required. Embankment outer surface failures are tolerated.

Further stability verification and analysis shall be undertaken in the presence of soils potentially liquefiable under seismic stress. In these cases, conservative engineering and construction requirements shall be incorporated to ensure a safety factor of at least 1.

The two (2) cases of stability under seismic stress (pseudo-static and liquefaction) shall be checked and verified independently.

Calculations in relation to earthquakes shall comply with regulatory requirements such as those of Part 5 of the "Foundations, retaining structures and geotechnical aspects" of Eurocode 8: "Calculation of structures for their resistance to earthquakes" as defined respectively by standards EN 1998-5 and EN 1998-5/NA (National Appendix). These two Eurocode 8 standards supplement Eurocode 7 – "Geotechnical calculations" in the case of seismic calculations.

## 5.15. Drainage system and bank protection

### 5.15.1. Drainage filter layers

The two types of earthwork shall ensure the following functions on a permanent basis:

- draining internal water from the bank by the drawdown of groundwater or catchment of intermittent water flow;
- preventing the deterioration of the mechanical properties of the materials to be drained;
- recovering low-level water from the track bed longitudinal drainage system or from a separate system.

The intrinsic mechanical properties of the filter layers shall be permanent.

Drainage filter layers that fulfil a mechanical stabilisation function shall be additionally justified vis-à-vis the stability of the bank and the track bed.

The anti-contamination function is ensured through compliance with Terzaghi's filter criterion between the drainage materials and the materials to be drained or, in the absence thereof, by adapting the particle size distribution of the material to the drained material (consistent particle size distribution along the contact surface with the existing ground).

The constituent materials of protective layers shall have a maximum aggregate size $D \leq 200$ mm. The maximum aggregate size shall not exceed third of the thickness of the layer. In case crushed rock is used for producing the unbound mixture, the resistance to fragmentation LA shall be ≤ 45.

**Placing geotextiles between the drainage filter layer and the bank to be drained is not allowed.**

### 5.15.2. Protective layers

Protective layers shall ensure the following functions on a permanent basis:

- prevent the modification of the surface bank material by preventing all modifications to its intrinsic properties;
- protect the materials in place from weathering, associated with different climatic situations (water, frost, sunlight).

The protective layers shall be designed also to respect the following instructions:

- the exterior gradient of the layer is parallel to the bank being protected;
- the layer is at least 0.5 m thick perpendicular to the bank being protected.

The constituent materials of protective layers shall have a aggregate size range of:

- d (Minimum diameter of grain size) = 0 mm;
- maximum aggregate size D ≤ 630 mm. The maximum aggregate size shall not exceed third of the thickness of the layer, so D has to be adapted in consequence;
- In case the aggregates are produced from crushed rock, the resistance to fragmentation LA shall be ≤ 40.

### 5.15.3. Riprap structures

Riprap structures shall protect the embankment base in flood risk areas against the aggressive action of floods.

Their intrinsic mechanical properties shall be permanent.

The particle size distribution of the material depends on the type and speed of run-off water.

## 5.16. Gabions

Requirements depend on the purpose of the structure:

- as bank protection, they shall provide protection against erosion;
- as low retaining structures, they shall be stable when resisting horizontal and vertical pressure;
- as protection against rockfall, they shall be resistant to foreseeable shocks and prevent the passage of rocks;
- as noise barriers they shall be stable and provide the expected reduction in noise.

Metal lattice cages are to be made of galvanised steel wire in accordance with the EN 10223-8 product specification.

**Gabions may not be used to shore up railway earthworks.**

## 5.17. Re-Vegetation

The re-vegetation phase involves spreading topsoil on the earthwork improvements and associated structures, including seeding and planting as required.

The objectives and requirements of this operation are to:

- reduce the risk of washout of the infill material, erosion and deterioration of the embankment slopes by their prolonged exposure to detrimental weather conditions;
- to help to stabilize the surface of cutting and embankment slopes;
- to avoid the proliferation of weeds;
- to integrate the earthwork improvements into the landscape.

A minimal thickness of 0.15 m perpendicular to the slope is required to prevent gullies.

This protection shall be implemented as quickly as possible and shall be effective over the design working life of the structure.

Technical solutions shall be offered according to the requirements listed above, although other alternatives that meet the same objectives may be proposed.

## 5.18. Track bed structure

The dimensions (thicknesses) of the railway track bed layers (ballast layer, subballast layer and prepared subgrade layer) shall be designed in accordance with the UIC 719R "Earthworks and railway track beds" or equivalent, taking into account following key aspects:

- Required bearing capacity (P3 according to UIC 719R);
- Subgrade properties (e.g. bearing capacity, moisture conditions and frost susceptibility);
- Hydrological and hydrotechnical conditions;
- Climatic conditions (e.g. frost penetration depth);
- Expected traffic volumes, axle loads and speed;
- Track properties.

### 5.18.1. Protection against frost

If subgrade soil is found to be frost-susceptible, different options to mitigate it shall be consider while designing the embankment – soil replacement, preventing the water intrusion into the soil (vertical and horizontal water movement) with different measures or preventing the frost penetration into the frost susceptible soil (increasing the thicknesses of structural layers or using insulating layers), especially under unfavourable hydrological and hydrogeological conditions.

The materials used for track bed layers (subballast and prepared subgrade) shall not be frost susceptible.

Following key values for **frost penetration depth** per country should be considered when designing the embankment:

| Country | Maximum frost penetration depth |
|---|---|
| Estonia | 2,05 m |
| Latvia | 1,74 m |
| Lithuania | 1,70 m |
| NOTE: These values can further be elaborated based on specific studies (e.g. based on meteorological data, calculated Frost Index, direct measurements, etc.) | |

### 5.18.2. Subballast layer

The subballast layer acts as a support for the ballast and its' main functions, throughout the expected service life, are to:

- reduce the stress of the applied loads from ballast layer to the layers below (i.e. prepared subgrade and embankment);
- contribute to the bearing capacity of the track;
- provide frost protection;
- drain water out of the track (permeable);
- act as a filter layer between two layers (i.e. prepared subgrade and ballast) in order to prevent intermixing.

Appropriate properties shall be defined in the technical design, taking into account the functions mentioned above.

The subballast layer shall be built from unbound mixture (produced according to EN 13242 and EN 13285). The table below describes the minimum requirements for subballast material.

| Property | Reference | Requirement |
|---|---|---|
| Mixture designation | EN 13285 Ch. 4.3.1 | 0/32, 0/45, 0/56 |
| Fines content | EN 13285 Ch. 4.3.2 | UF 5 |
| Oversize | EN 13285 Ch. 4.3.3 | OC 90 |
| Grading category | EN 13285 Ch. 4.3.4 | $G_B$ |
| Percentage of crushed or broken particles and totally rounded particles | EN 13242 Ch. 4.5 | $C_{50/30}$ |
| Resistance to fragmentation | EN 13242 Ch. 5.2 | $LA_{30}$ |
| Resistance to frost | EN 13242 Ch. 7.3 | $F_2$ |
| Content of harmful fines ($MB_F$ value) [(a)*] | EN 13242 Ch. 4.7 | ≤10 g/kg |
| NOTE: (a) – applicable if fines content is above 3%, please see EN 13242 Annex A. | | |

**Applicable only for prepared subgrade treated with hydraulic bonding agents*

*NOTE: Above described properties and requirements are minimum requirements that can be made stricter depending on the conditions in place of use (e.g. annual traffic volumes, permissible axle loads, design speed, studies etc.). Please see UIC 719R for more information for setting the appropriate requirements.*

The subballast layer shall be built with inorganic mineral material, free of humus. The content of particles below 0,02 mm shall be less than 3%.

The subballast layer shall have the following main characteristics:

- Minimum thickness: 0.32 m;
- Cross slope: 4 %;
- Slope: 3H/2V;
- Minimum bearing capacity on top of the subballast layer shall be $E_{V2}$ ≥ 120 Mpa (measured in accordance with DIN 18134);
- Target degree of compaction $D_{pr}$ ≥ 103% (EN 13286-2 standard Proctor);

- If necessary, the slopes of the subballast layer shall be protected with appropriate geogrids.

If there's an identified risk of cavities in the subsoil, the intrusion of water into the subsoil shall be prevented and for that purpose appropriate geosynthetic barriers shall be used. The barrier shall have at least same design working life as the structure.

### 5.18.3. Prepared subgrade

The prepared subgrade acts as a support for the track bed layers (i.e. ballast and subballast layers) and allows the subballast layer to be put into place. Additionally, the prepared subgrade contributes to the protection of the structure against frost, i.e. reduce the frost penetration depth if materials with insulating properties are used (i.e. sand, sandy gravel).

Prepared subgrade can be built from soils which meet the QS3 soil quality class requirements according to UIC 719R. Appropriate properties shall be defined in the technical design, taking into account the functions of the layer. The required properties for soils used for constructing the prepared subgrade shall be defined based on properties and categories described in EN 13242 and/or EN 13285. The material shall meet the minimum requirements described in the table below.

| Property | Reference | Requirement |
|---|---|---|
| Mixture designation<br>Maximum aggregate size D [a] | EN 13285 Ch. 4.3.1 | D ≤ 63 mm |
| Fines content | EN 13285 Ch. 4.3.2 | UF 5 |
| Oversize | EN 13285 Ch. 4.3.3 | OC 90 |
| Grading category | EN 13285 Ch. 4.3.4 | $G_V$ |
| Resistance to frost [b] | EN 13242 Ch. 7.3 | $F_4$ |
| Content of harmful fines ($MB_F$ value) [c] | EN 13242 Ch. 4.7 | ≤10 g/kg |

Notes:
(a) – upper size D shall be selected based on the requirement for Coefficient of Uniformity ≥ 6;
(b) – applicable to unbound mixtures produced from gravel and crushed rock. Not applicable to natural sand (Sa), gravelly sand (grSa) or sandy gravel (saGr);
(c) – applicable if fines content is above 3%, please see EN 13242 Annex A.

*NOTE: Above described properties and requirements are minimum requirements that can be made stricter depending on the conditions in place of use (e.g. annual traffic volumes, permissible axle loads, design speed, studies etc.). Please see UIC 719R Ch. 2.6 for more information for setting the appropriate requirements.*

The prepared subgrade shall be built with inorganic mineral material, free of humus. The content of particles below 0,02 mm shall be less than 3%.The prepared subgrade shall have the following main characteristics:

- Thickness calculated based on UIC 719R (depending on soil quality class of embankment fill or excavated surface) and frost penetration depth;
- Cross slope: 4 %;
- Slope: 3H/2V;
- Minimum bearing capacity measured in accordance with DIN 18134 on top of the prepared subgrade layer shall be:
  - $E_{V2}$ ≥ 80 MPa for untreated prepared sugrade;
  - $E_{V2}$ ≥ 120 MPa for treated prepared subgrade.

- Target degree of compaction $D_{pr}$ ≥ 100% (EN 13286-2 standard Proctor);
- If necessary, the slopes of the prepared subgrade layer shall be protected with appropriate geogrids.

**It is obligatory for any proposal involving the adoption of a prepared subgrade made of treated material to be justified and compared to a solution using untreated prepared subgrade.**

**Prepared subgrade treated with hydraulic bonding agents is forbidden on compressible soils.**

## 5.19. Geosynthetics

Geosynthetics are structural elements used mainly to provide following functions (according to EN ISO 10318-1):

- Drainage;
- Filtration;
- Protection;
- Reinforcement;
- Separation;
- Surface erosion control;
- Barrier;
- Stress relief:
- Stabilization.

If the usage of geosynthetics is technically and economically justified, thenappropriate properties shall be defined in the technical design, based on NorGeoSpec 2012 (if applicable), applicable product specification, depending on the intended use, for example:

- EN 13250 “Geotextiles and geotextile-related products - Characteristics required for use in the construction of railways”;
- EN 13251 “Geotextiles and geotextile-related products - Characteristics required for use in earthworks, foundations and retaining structures”;
- EN 13252 “Geotextiles and geotextile-related products - Characteristics required for use in drainage systems”;
- EN 13253 “Geotextiles and geotextile-related products - Characteristics required for use in erosion control works (coastal protection, bank revetments)”;
- EN 13256 “Geotextiles and geotextile-related products - Characteristics required for use in the construction of tunnels and underground structures”;

- EN 15381 "Geotextiles and geotextile-related products - Characteristics required for use in pavements and asphalt overlays".

Geosynthetic materials must have at least same design working life as the embankment/layer in which these products are going to be used.

## 5.20. Upper embankment

The upper embankment (the top level of the embankment or the excavated surface) supports the prepared subgrade and shall allow it to be put into place.

In compaction terms, a target degree of compaction $D_{pr} \geq 97\%$ (EN 13286-2 standard Proctor) shall be achieved.

The $E_{V2}$ modulus measured in accordance with DIN 18134 on top of the embankment shall be:

- $E_{V2} \geq 45$ MPa for fine soils
- $E_{V2} \geq 60$ MPa for sandy or gravelly soils
- $E_{V2} \geq 80$ MPa for treated soils.

Embankment/excavation material quality classes are defined in the UIC 719R (table 5).

# 6. Construction on sites with individual design

This chapter covers special designs in specific areas such as:

- embankments in floodplains;
- embankments in marshlands;
- embankments in damp areas;
- embankments built underwater;
- embankments on compressible soils;
- technical blocks;
- embankments built with acoustic screens.

## 6.1. Embankments

### 6.1.1. Geometrical characteristics

At a primary hypothesis, the slope of the embankments shall be considered at 1V / 2H. The parameters of the slopes depend on the characteristics of embankment materials available and shall be verified by calculations.

The crossing slope at the top and bottom is 4% to allow drainage.

- Upper Section of the Earthworks (USE) / bottom of prepared subgrade:

There are no particular stipulations with regard to the upper section of the earthworks. To allow for placing geotextiles and the prepared subgrade, the bearing capacity of upper section of the earthworks must be sufficient. The single purpose is to obtain the final bearing capacities at the top of the prepared subgrade and subballast layers.

### 6.1.2. Common embankments

The typical cross section of a common embankment is RBDG-DWG-001.

The height of common embankments is between 1.50 m and 12 m.

If slope stability cannot be ensured, other assumptions may be added. For example, it can be decided to add berms to each side of the embankment, reducing the slope, etc. These assumptions shall be verified by calculations.

On soft soils and in compressible areas, replacement or soil reinforcement (such as stone columns, rigid inclusions, etc.) shall be performed under the embankments (see chapter 6.1.6).

The thickness of the topsoil (perpendicular to the slope) is to be equal to 0.15 m.

If the vegetation considered needs a high thickness of topsoil, the self-stability of the topsoil shall be checked by calculation and if necessary, a geogrid could be used to stabilize the slope.

### 6.1.3. Low rise embankments

The height of low rise embankments is:

- Inferior to 1.50 m between the Zp and the natural ground level;
- Inferior to 1.20 m between the edge of the top of the sub-ballast layer and the natural ground level.

Low rise embankments require the same verification as common embankments, but their drainage must be designed as if the structure is a cut, that means with at least 1.5m between the drainage invert level of the drainage and the Zp altimetry.

### 6.1.4. High embankments

The high embankment is an embankment with a height of ≥ 12 metres.

To ensure stability and accessibility for maintenance, berms of 5 m width are to be systematically created (minimal width for accessibility of 5m but shall be justified by calculation for stability and be larger if needed). Berms can be suitable for motor vehicles.

Particular attention should be given to materials for the base of embankments: granular materials or treated materials. Their stability shall be checked by means of calculations (see chapter 5.3).

On soft soils and in compressible areas, replacement or soil reinforcement (such as stone columns, rigid inclusions…) shall be performed under the embankments (see chapter 6.1.6).

The thickness of the topsoil (perpendicular to the slope) is considered equal to 0.15 m.

If the vegetation considered needs a high thickness of topsoil, the self-stability of the topsoil shall be checked by calculation and if necessary, a geogrid could be used to stabilize the slope.

### 6.1.5. Embankments in floodplains

The typical cross section of an embankment in a floodplain is RBDG-DWG-022.

The embankment is to consist of granular, non-water-sensitive material on a thickness equal to the high-water level (HWL) + 0.5m. If HWL is higher than the limit between the embankment and prepared subgrade, the entire embankment is to be of non-water-sensitive material. The slopes of the embankment will be improved according to the nature of available materials. If these materials are standard embankment materials, geotextiles shall be installed under the prepared subgrade.

The Zp has to be at least 1.50 m above the HWL.

Under the embankment, soft and waterlogged soils must be replaced.

### 6.1.6. Embankments on compressible soils

On soft soils and in compressible areas (including thixotropic soils), replacement or soil reinforcement (such as stone columns, rigid inclusions…) shall be performed under the embankments.

The depth of soil replacement and the spatial distribution of support piles or column will be determined based on stability and settlement studies.

### 6.1.7. Technical block

The typical cross sections of a technical block are:

- RBDG-DWG-030;
- RBDG-DWG-031;
- RBDG-DWG-032.

In order to avoid settlement at the exits of artificial structures, technical blocks have specific requirements:

- soil reinforcements under the technical block (stone columns, rigid inclusions, etc…);
- full replacement of compressible soils.

On a length of 20 m, the sub-ballast and subgrade are to consist of a treated sandy gravel mixture, in accordance with the provisions of chapter 5.7, on a thickness of 0.8m.

On a length of 5m at least, the embankment consists of intermediate solid blocks. At the exit of the bridge, on a length of 1m at least, the embankment consists of treated materials.

The technical block geometry depends on:

- the type of the structure type;
- the height of the structure;
- the construction sequences.

### 6.1.8. Embankments with acoustic screens

The typical cross section of an embankment with acoustic screen is RBDG-DWG-020.

On embankments (including level embankments) where acoustic screens are necessary, the track formation width is to be increased by at least 1 m on the side concerned by the acoustic screens.

## 6.2. Cuttings

### 6.2.1. Geometrical characteristics

At this stage of study, the slopes are at 2H / 1V. The choice of the slopes will depend on the quality of embankment materials available and shall be verified by calculations.

The crossing slopes are at 4% to allow drainage.

### 6.2.2. Geometrical characteristics

The typical cross sections of an ordinary cutting are:

- RBDG-DWG-003;
- RBDG-DWG-004.

The depth of an ordinary cutting is less than 12 m.

A width is to be preserved on each side of the prepared subgrade. The drainage channels will be located in this strip.

To ensure drainage and to avoid landslides, drainage filter layers are to be inserted on the slopes of cuttings. The thickness considered is 0.5 m min. perpendicular to the slope.

On draining or protective materials, topsoil is to be added. A thickness of 0.15 m of topsoil perpendicular to the slope is considered.

### 6.2.3. Deep cuttings

The typical cross section of a deep cutting is RBDG-DWG-005.

The depth of a deep cutting is more than 12 m.

Berms are systematically built at mid-slope to ensure cutting stability and accessibility. Berms shall be suitable for motor vehicles; their width shall be at least 4 m (or larger depending on stability calculation results). The suitability for motor vehicles shall be defined by specified study base on local practices.

Stability shall be checked by means of calculations (see chapter 5.2).

To ensure drainage and to avoid landslides, drainage filter layers are to be inserted on the slopes of cuttings. The thickness considered is 0.5 m min. perpendicular to the slope.

On draining materials, topsoil is to be added. A thickness of 0.15 m of topsoil perpendicular to the slope is considered.

A geotextile is to be inserted between the prepared subgrade and the natural soil to avoid contamination by fine particles.

To limit size of the right of way, preference is to be given to building the lineside maintenance road on the mid-slope berm. At the base of the slope of the cutting, separate drainage is to be provided. A drainage collector will recover the water from roadway. On the other side of the roadway berm there will be a ditch.

## 6.3. Revegetation - Vegetation – Slope protection

Special attention is to be paid to slope protection against the effects of weather, frost and thaw, etc…

Revegetation on track bed slope (including sub-ballast layer and prepared subgrade) shall be avoid, therefore, geogrids can be used if necessary on these particular slopes.

Revegetation and seeding should be carried out:

- on ordinary, and high-height embankments;
- on natural soil and/or draining and/or protective layers on cuttings.

It shall be planted on a layer of topsoil. The thickness considered at this stage of study is equal to 0.15 m perpendicular to the slope.

The seeding and planting of the surface for vegetation shall be in accordance with the instructions given in chapter 5.1.

## 6.4. Cavities

Special designs will be necessary in the areas where a risk of cavities has been identified:

- geosynthetics;
- filler injections;
- concrete slabs, etc…

Geosynthetics prevent the sudden failure of the embankment when a sinkhole is formed.

# 7. Design of Earth bed at operating points (Technical Stops and Workbases)

The same assumptions as those retained for the high-speed line were taken into account. In particular for embankments in flood plains, marshlands, damp areas and compressible soils.

Topsoil shall be stripped and replaced over the whole area.

Design solution with only prepared subgrade layer without subballast layercan be used, if the structure is not frost susceptible to necessary depth and $E_{V2} \geq 120$ MPa is achieveable.

# 8. Strategy regarding materials

## 8.1. Re-use of materials

- Reuse of materials - overview

Re-use of site materials is acceptable, thus reducing the use of temporary or existing quarries and depots, while also taking into account constraints imposed by the project environment and overall project budget.

- Reuse of material - requirements

Re-used materials shall comply with the same construction, compaction and geometry preservation criteria as virgin materials used over the design life.

Coarse materials for railway embankments shall maintain a granular distribution with a maximum size (D) of 630 mm.

## 8.2. Excavations and Quarries

The Rail Baltica railway project requires a large amount of material especially:

- materials for embankments;
- materials for the subballast layer and prepared subgrade layer;
- materials for flood, marshlands and damp areas;
- materials for drainage filter and protection layers;
- materials for technical blocks.

# 9. Minimum Handover Criteria

This chapter describes the minimum handover criteria which shall be taken into account when drafting the QA/QC documentation by the designer. Since the final requirements will depend on the proposed technical design provided by the designer, not all the necessary topics are covered by this chapter. The requirements described here outline the principles and typical frequencies for the QA/QC testing. Additionally, the test frequencies stated in this Chapter don't exclude the possibility to take additional steps during the construction process to verify the materials and earthworks. The Client's representative or Engineer can organize additional testing as it sees fit.

This Chapter is divided into three main parts (topics):

- Soils and aggregates
- Compaction degree $D_{pr}$ and $E_{V2}$ of the structural layers
- Geometry of the substructure layers.

## 9.1. Soils and aggregates

Embankments

Soils and constructionmaterials used for constructing the embankment shall meet all the requirements described in the proposed technical design (e.g. soil classification according to EN 14688-1, EN 14688-2, UIC 719R and frost susceptibility criteria). All required properties shall be verified at least **once per 2000 m$^3$** (per source/quarry). If applicable, physical, chemical and durability-related properties according to EN 13242 (resistance to fragmentation, frost resistance, etc.) shall be assessed at least **once per 10 000 m$^3$** (per source/quarry).

Prepared subgrade

Prepared subgrade materials must meet the requirements stated in the proposed technical design. The grading shall be checked at least **once per 1000 m$^3$** (per source/quarry). If applicable, other geometric, physical, chemical and durability-related properties (resistance to fragmentation, frost resistance, etc.) shall be assessed at least **once per 5000 m$^3$** (per source/quarry).

Subballast

Subballast materials must meet the requirements stated in the proposed technical design. The grading shall be checked at least **once per 1000 m$^3$** per source. In case other requirements (e.g. physical, chemical and durability-related properties) are applicable, the tesing frequency of those properties can be extended to at least **once per 5000 m$^3$** per source.

## 9.2. Compaction and $E_{V2}$ modulus

Compaction requirements and $E_{V2}$ modulus for different structural layers are described in the table below.

| Layer | $E_{V2}$ (DIN 18134) | | $D_{pr}$ (EN 13286-2 standard Proctor) | |
|---|---|---|---|---|
| | Target value | Testing frequency | Target value | Testing frequency |
| Subballast | ≥ 120 MPa | Once per 100 m 2 locations - beneath the | ≥ 103% | Once per 20 m 2 locations - beneath the |
| Prepared subgrade | ≥ 80 Mpa (untreated material) | | ≥ 100% | |

| | | | | |
|---|---|---|---|---|
| | ≥ 120 Mpa (treated material) | railway and near the edge | | railway and near the edge |
| **Upper embankment (embankment/excavate surface)** | ≥ 45 Mpa for fine soils ≥ 60 Mpa for sandy or gravelly soils ≥ 80 Mpa (treated material) | | ≥ 97 % | |

DIN 18134 and EN 13286-2 are reference methods. During the construction phase, different direct/indirect test methods (e.g. continuous compaction control (CCC) method, deflectometers (LWD, FWD), $E_{V2}/E_{V1}$, Troxler, etc.) can be used if the correlation with the reference method is documented and/or verified with trial section.

Compaction measurements can be waived by the Engineer (supervision), if the material is unsuitable for conducting such tests or indirect methods are applied which are calibrated with trial section(s). Compaction requirements can be waived also if Continuous Compaction Control (CCC) is applied. In case CCC is used, $E_{V2}$ measurements are done only for “soft spots” to check the compatibility of these locations with the requirements. Roller compactor must be equipped with GPS and the results shall be recorded with an accuracy of ≤0,2 m

## 9.3. Geometry

Allowable geometrical deviations for different structural layers are described in the tables below.

<table>
<tr><th>Structure</th><th>Property</th><th>Allowable deviation, single measurement</th><th>Allowable deviation, average (5 measurements)</th><th>Method</th><th>Frequency</th></tr>
<tr><td rowspan="6">Embankments/cuttings</td><td>Height</td><td>± 50 mm[a]</td><td>+20 mm<br>-50 mm</td><td>Geodetic</td><td>20 m</td></tr>
<tr><td>Width</td><td colspan="2">+150 mm<br>- 50 mm[b]</td><td>Geodetic<br>or<br>Tape measure</td><td>20 m</td></tr>
<tr><td>Slopes</td><td colspan="2">Not steeper than designed</td><td>Geodetic</td><td>In case of suspection</td></tr>
<tr><td>Crossfall</td><td colspan="2">±1,0%</td><td>3m straightedge</td><td>20 m</td></tr>
<tr><td>Alignment</td><td colspan="2">± 100 mm</td><td>Geodetic</td><td>20 m</td></tr>
<tr><td>Evenness</td><td colspan="2">± 50 mm</td><td>3m straightedge</td><td>In case of suspicion</td></tr>
<tr><td colspan="6">NOTES:<br>(a) – for rockfill embankments the allowable deviation is ± 100 mm<br>(b) – for rockfill embankments the allowable deviation is – 100 mm</td></tr>
</table>

<table>
<tr><th>Structure</th><th>Property</th><th>Allowable deviation, single measurement</th><th>Allowable deviation, average (5 measurements)</th><th>Method</th><th>Frequency</th></tr>
<tr><td rowspan="6">Prepared subgrade</td><td>Height</td><td>± 50 mm</td><td>+20 mm<br>-50 mm</td><td>Geodetic</td><td>20 m</td></tr>
<tr><td>Width</td><td colspan="2">+150 mm<br>- 0 mm</td><td>Geodetic<br>or<br>Tape measure</td><td>20 m</td></tr>
<tr><td>Slopes</td><td colspan="2">Not steeper than designed</td><td>Geodetic</td><td>In case of suspection</td></tr>
<tr><td>Crossfall</td><td colspan="2">±1,0%</td><td>3m straightedge</td><td>20 m</td></tr>
<tr><td>Alignment</td><td colspan="2">± 100 mm</td><td>Geodetic</td><td>20 m</td></tr>
<tr><td>Evenness</td><td colspan="2">± 30 mm</td><td>3m straightedge</td><td>In case of suspicion</td></tr>
</table>

<table>
<tr><th>Structure</th><th>Property</th><th>Allowable deviation, single measurement</th><th>Allowable deviation, average (5 measurements)</th><th>Method</th><th>Frequency</th></tr>
<tr><td rowspan="2">Subballast</td><td>Height</td><td>± 50 mm</td><td>± 20 mm</td><td>Geodetic</td><td>20 m</td></tr>
<tr><td>Width</td><td colspan="2">+50 mm</td><td>Geodetic</td><td>20 m</td></tr>
</table>

| | | | | | |
|---|---|---|---|---|---|
| | | - 0 mm | | or<br>Tape measure | |
| | Crossfall | ±0,5% | | Geodetic<br>or<br>3m straightedge | 20 m |
| | Alignment | ± 100 mm | | Geodetic | 20 m |
| | Thickness | ± 10% | ± 5% | | |
| | Evenness | ± 20 mm | | 3m straightedge | In case of suspicion |

# 10. Requirements for aggregates

[Text in this Chapter has been deleted intentionally]