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Earthworks - Part 1: Principles and general rules

Erdarbeiten - Teil 1: Grundsätze und allgemeine Regeln

Terrassement - Partie 1 : Principes et règles générales

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Erdarbeiten - Teil 1: Grundsätze und allgemeine Regeln

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
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European foreword

This document (prEN 16907-1:2016) has been prepared by Technical Committee CEN/TC 396 “Earthworks”, the secretariat of which is held by AFNOR.

This document is currently submitted to the CEN Enquiry.

This document is one of the European Standards within the framework series of EN 16907 on *Earthworks*, as follows:

— *Part 1: Principles and general rules* (this document);

— *Part 2: Classification of materials;*

— *Part 3: Construction procedures;*

— *Part 4: Soil treatment with lime and/or hydraulic binders;*

— *Part 5: Quality control;*

— *Part 6: Land reclamation with dredged hydraulic fill;*

— *Part 7: Hydraulic placement of mineral waste.*

Introduction

Earthworks are a civil engineering process aimed at creating earth-structures by changing the geometry of the earth surface for construction or other activities. Application fields of earthworks are associated with:

- transport infrastructures (road and motorways, railways, waterways, airports);
- platforms for industrial, commercial and residential buildings;
- water engineering, flood defence and coastal protection works;
- harbours and airport areas, including the construction of embankments in water;
- river dykes and marine embankments for land reclamation;
- earth and rock fill dams;
- onshore embankments made of hydraulically placed fill;
- landscaping embankments;
- backfilling of open mines;
- tailing dams;
- etc.

They are characterized by the need to use available natural or recycled materials and to handle them in a way appropriate to yield prescribes properties.

The set of standards prepared by CEN/TC 396 is divided into several parts, which correspond to different steps of the planning, execution and control of earthworks and should be considered for executing earthworks:

- Part 1: Principles and general rules (this document);
- Part 2: Classification of materials;
- Part 3: Construction procedures;
- Part 4: Soil treatment with lime and/or hydraulic binders;
- Part 5: Quality control;
- Part 6: Land reclamation with dredged hydraulic fill;
- Part 7: Hydraulic placement of mineral waste.

These “Earthworks standards” do not apply to the environmental planning and geotechnical design that determines the required form and properties of the earth-structure that is to be constructed (these aspects are covered in other European Standards). They apply to the design of the earthworks materials, execution, monitoring and checking of earthworks construction processes to ensure that the completed earth-structure satisfies the geotechnical design.

1 Scope

This European Standard (Part 1) gives definitions, principles and general rules for the planning, design and specification of earthworks. It introduces the other parts of the standard, which need to be used together with Part 1.

It is applicable to all types of earth-structures, whatever their intended use is (roads, railways, airfields, waterways, buildings, landfills, tailing dams, etc.), except where listed below:

— some specific types of works such as the execution of trenches and small earthworks may be organized using simplified or specific rules;

— some structures, such as dykes and dams, need earthworks which have specific design and construction requirements: these may extend beyond the rules of this standard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1997-1, *Eurocode 7: Geotechnical design - Part 1: General rules*

EN 1997-2: 2007, *Eurocode 7 - Geotechnical design - Part 2: Ground investigation and testing*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
earthworks
civil engineering process that modifies the geometry of ground surface, by creating stable and durable earth-structures

3.2
earth-structure
civil engineering structure, made of soils, rocks, by-products or recycled materials, resulting from earthworks (cutting, embankment)

3.3
design of earthworks
defining of the construction process to produce a specified earth-structure

3.4
materials
all soils, rocks, by-products and recycled materials handled during earthworks

Note 1 to entry: Materials do not include binders, geosynthetics and other materials, which are designated by their own name.

3.5
fill material
material used for the construction of an embankment

3.6
embankment
any earth-structure formed by the placement of fill material in a controlled manner (including the infilling of large excavations, and earth-structures formed by dredging)

3.7
embankment zone
subdivision of an embankment, such as the base, the core, the shoulders and the upper zone

3.8
superstructure
any type of civil engineering construction placed on top of an embankment

Note 1 to entry: Examples of superstructure are road, rail track, building, etc.

3.9
capping layer
specific transition layer, part of the upper zone, placed below the superstructure

3.10
cutting
structure produced by excavating ground

Note 1 to entry: The geometry of earth-structures and parts of them (layers, surfaces, etc.) are not always described in the same way in different languages and countries. Drawings explaining the meaning of these geometric terms are given in informative Annex B.

4 Principles of earthworks design and execution

4.1 General

Earthworks include to extract, load, transport, transform/improve, place, stabilize and compact natural materials (soils, rocks), by-products or recycled materials in order to obtain stable and durable cuttings, embankments or engineered fills, with prescribed properties. These works may be executed underwater. Earthworks require planning, design, construction and maintenance. They depend on the properties on the materials, the required properties of the structure and the environment.

This document gives rules relative to the organization of earthworks projects and their design and planning.

4.2 Stages of earthworks projects

Each earthworks project consists of two main stages:

— pre-construction studies, including:

  — the analysis of the earth-structure to be built;

  — site investigations and classification of materials (prEN 16907-1:2016, Clause 5 and prEN 16907-2:2015, Clause 5);

  — assessment of the compatibility of these materials with the required properties of the earth-structure (prEN 16907-1:2016, Clauses 6, 7, 8 and 9);

  — selection of a construction procedure (prEN 16907-1, -3, -6 and -7);

   - optimization of earthworks at the scale of the whole project (prEN 16907-1:2016, Clause 11);
   - specifications for executing the works (construction procedure, monitoring, quality control) (prEN 16907-1, -3, -5, -6 and -7);
- execution of works (construction):
   - installation on site;
   - checking the design assumptions (that may be revised, if necessary);
   - execution of works as specified;
   - monitoring;
   - quality assessment;
   - checking the characteristics of the completed earth-structure vs. the requirements, leading to the acceptance of the results of the earthworks.

4.3 Instructions for the execution of works

The design of earthworks shall produce detailed instructions to be imposed on the execution of works (Parts 3 to 7). These instructions include such items as:

- for building sites:
   - type and consistency of the area to be worked with;
   - foundation level, type of foundation and construction of buildings nearby;
   - type and consistency of existing enclosure or retaining structures;
   - type, position, dimension and owner of natural or artificial cavities and obstacles (anchors, geosynthetics, stone columns, sealing bodies, grouted material, etc.);
- for embankments and cuttings:
   - quantity (volume), type, position, dimensions and structure of the earth-structures;
   - quantity, type, position, dimensions, formations and purpose of construction pits and trenches, including minimum dimensions of the working space;
   - inclination of slopes and development of berms;
   - deviations from the specified dimensions for ablation or removal profiles; especially for planum and coating thickness;
   - protection for construction pits and trenches, embankments and slopes;
   - efforts related to the laying and reconstruction of the protection for construction pits and trenches, embankments and slopes;
   - keeping a protective layer above foundation level, thickness of the protective layer and moment of removal;

- description and classification of soils, rocks and other materials, en accordance with Part 2;
- main differences to do with properties and conditions of soils, rocks and other materials before and after excavation;
- constraints concerning the use of specific materials, especially by-products and recycled materials;
- usage, treatment and processing of soils, rocks and other materials as well as type of laying or other uses;
- type, position, length, conditions and potential restrictions on the usage of transportation routes;
- type and possibilities of storage place;
- usage of soils for planting purposes;
- type and scope of verifications of suitability and certificates of quality requested by the Contractor for materials to be delivered;
- requirements and proofs of compaction;
- guidelines resulting from expert's reports — specially for geotechnical reports and hydrogeology — and to what extent those guidelines should be followed concerning the execution;
- guidelines resulting from water law permits;
- collection and derivation of surface water from neighbouring areas as well as groundwater, stratum water, spring water and leachate;
- development of access from the earthworks to the other constructions;
- installation of geosynthetic material;
- quantity, type, position, dimensions and masses of installation, i.e. level of settlement, shaft rings, pipes;
- guidelines resulting from geotechnical calculations and analyses;
- cleaning of construction elements that were laid open;
- protection and security measures for construction at risk.

4.4 Design of earthworks and design of earth-structures

The design of earthworks differs from the design of earth-structures.

The design of earth-structures in terms of stability and deformations is ruled by EN 1997 (Eurocode 7) and other relevant standards. Geotechnical and structural design produces the requirements put on the properties and functions of the completed structure (geometry, stiffness, bearing capacity, permeability…). The standards on earthworks all assume that the earth-structure to be built has been properly designed.

For earthworks, "designing" means "defining the process" enabling to transform natural *in situ* ground (soil or rock) and/or by-products or recycled materials into a well compacted and durable embankment with the required properties or a stable cut. This decision process includes the characterization of natural ground, the choice of suitable equipment and rules to plan extraction, transport, compaction and control of the materials. The products of this design include risk assessment reports, execution plans, time-tables, work-flow schemes, etc. These conditions may be met by experience-based prescriptions or by performance-based design.

Design of earthworks shall account for:

— the type of structure (cutting, embankment, etc.);

— the required properties of the completed structure;

— the nature and state of materials to be handled (prEN 16907-2);

— the hydrogeological and meteorological contexts;

— the importance of the earth-structure to be built;

— the type of available equipment to perform the works (prEN 16907-3);

— the possibilities offered by material treatment for fill construction (prEN 16907-4);

Design prepares specifications for executing the works (prEN 16907-3, -4, -6, -7);

The specifications resulting from the design phase describe the details of the construction process. They shall be used to prepare the monitoring and quality control procedures. Specifications include:

— the assumed nature (classes) of materials, which shall be checked during the execution of works,

— the mechanical process used for extraction, transport, layering, eventual treatment with binders or areation/humidification and compaction;

— the destination of every volume of excavated material;

— the location of temporary or permanent disposals;

— the schedule of operations;

— the climatic restrictions, for example how to proceed at temperatures close to freezing;

— the procedures and planning of monitoring and control activities during the execution of the works;

— requirements for the protection of the earthworks to avoid deterioration of the fill material or subgrade.

Earth-structure design strongly depends on the available materials and the possibility to reach the expected result through earthworks. Designers are therefore expected to at least globally account for earthworks design when they design earth-structures. Consideration shall be given to available materials, site conditions, land requirements, including all temporary works and the limitation of environmental impact during the construction phase, in use and for future maintenance operations.

Site conditions include:

— constraints due to nature: physical adaptation to the site (topography, geology, geomorphology, hydrogeology, climate, and climate change, use of land), floods, landslides, old mines, etc.;

— constraints due to: archaeology/historical heritage, the environment, the owners and inhabitants, unexploded ordnance (bombs), etc.;

— constraints due to existing service lines (e.g. high tension electric lines, water, oil and gas pipelines).

These constraints are normally considered in the civil engineering project and are outside the scope of this standard.

4.5 Earthworks, sustainable development and the environment

Earthworks should be designed with sustainability in mind. For the purpose of this European Standard, sustainable development is taken to mean: "an enduring, balanced approach to economic activity, environmental responsibility and social progress". Some aspects of sustainable development are covered at the level of the project and not directly linked to the execution of earthworks.

Examples of contributions of earthworks to sustainable development are:

— the preservation of natural resources by optimising the re-use of site materials;

— the limitation of heavy vehicles traffic to bring materials to the construction site;

— the reduction of the externalisation of stockpiles and borrow pits;

— the use of techniques with low environmental impact, such as aeration or the use of industrial by-products;

— the diminution of energy consumption for transport and compaction of fills and the reduction of emitted gases (carbon dioxide);

— the decrease of water consumption (ploughing sprinkler, dust fixing products);

— the optimization of costs and duration of works.

Environmental considerations concern either the completed earth-structure or the execution of earthworks. This European Standard deals with effects of earthworks only (Part 3). Consideration shall be given to:

— noise and vibrations;

— road traffic;

— waste and contaminated ground management;

— dust production, including binders in case of fill material treatment;

— pollution of air and water;

— onsite and offsite disposal of excess or unsuitable materials.

All these environmental questions shall be answered with respect to existing laws, standards and other good practice rules.

The presence of polluted soils and possible use of manufactured or recycled materials of industrial or mining processes should be considered from the beginning of a project to maximize chances of re-use.

4.6 Risk management

The management of risk should be a key aspect of complex projects involving earthworks as in all construction activity. The areas of risk to be managed include:

— programme, quality and financial risks to ensure the successful delivery of the project;

— health and safety, along with environmental risks to satisfy statutory requirements.

On large or complex earthworks projects, it can be advantageous if each design team develops and maintains a risk register for the element of the works that they are responsible for.

Special risks for earthworks projects are related to geotechnics like:

- unknown site conditions due to inadequate soil investigation;
- the impact on adjacent structures/infrastructure;
- the sensitivity of the soils together with the weather during execution (and more generally, the climate);
- the failure of drainages and dewatering systems;
- the safety of dams and slopes; and
- the environment (e.g. building in protected areas, use of dangerous substances).

In the case of earthworks, the risks are likely to be captured within a geotechnical risk register, which can be used to enable the design team to manage out or minimize some of the risks associated with the earthworks element of the project. All residual risks should be managed at the global project level.

4.7 Types of earthworks

Earthworks encompass a large range of activities, which cannot be covered by a unique set of rules. Experience and existing rules apply to one of the following four types of works, which serve as a guide for the parts and clauses of this standard:

— construction of embankments (prEN 16907-1, -3, -4, -5 and -6:2015, Clause 6);

— execution of cuts and excavations (prEN 16907-1, -3:2015, Clause 7);

— hydraulic placement of dredged material (prEN 16907-1 and -6:2015, Clause 8);

— hydraulic placement of soils and mineral waste (prEN 16907-1 and -7:2015, Clause 9).

5 Specific site and material investigations

5.1 Information needed for earthworks design

The description, identification, classification and characterization of soils, rocks and other fill materials are an essential part of the design of earthworks. They yield the necessary information to determine the nature of each material, the best way to take that material from excavations or cuttings, the final state it may reach after compaction and the best way to achieve this final state.

The description of natural and man-made materials for earthworks should cover:

— the type of material (soils, rocks, other materials);

- the presence of pollutants;
- the presence of organic matter and evolving or reactive minerals (gypsum, soluble salts, etc.);
- all necessary information to classify the materials (Part 2):
  - for soils: particle sizes, plasticity of clayey soils, etc.;
  - for rocks: origin, degradability, fragmentability, etc.;
  - for other materials: constituents, mineralogy, etc.;
- information on the initial state of natural soils and rocks (density, water content and grading of soils, discontinuities in rocks, etc.);
- the determination of the optimum compaction characteristics for fill materials;
- when necessary, an estimate of the deformability, resistance and permeability of the compacted material;
- any other information required for the project.

This information shall be used to enter the system of earthworks design which has been selected, based on specific full-scale compaction tests or on the use of classifications dedicated to earthworks.

5.2 Coordination of geotechnical investigations for earth-structure and earthworks

5.2.1 General

Geotechnical site investigations for an earth-structure project shall provide adequate and sufficient information for the design and construction of the new structure. Part of this information is ruled by EN 1997-2 and should cover the design of the completed structure and of the temporary slopes and structures created during the construction works. The geotechnical model shall cover the zone of influence of the structure, both for mechanical analysis and for hydrological and hydrogeological analysis. This European Standard considers only the ground properties, which are of importance for the execution of earthworks.

The stages of a geotechnical investigation should include a desk study (sometimes referred to as a preliminary sources study), a preliminary investigation, to characterize the site in general terms, and wherever required, subsequent phases of design investigation to provide detailed information for specific elements of the design.

Geotechnical investigations also include the detection and characterization of any infilling and old waste disposal sites, former mining areas or contaminated soils, depending on their nature and extent.

If pollution is suspected during exploration as a result of anthropogenic changes or geogenic material accumulations, the environmentally relevant parameters shall be determined.

5.2.2 Site investigations for geotechnical design

Earthworks create two main types of earth structures: “excavations and slopes” and “embankments”. These structures shall be designed following the rules of EN 1997-1, which consider stability, deformations and durability of each structure.

EN 1997-2:2007 identifies the need to plan the investigations to provide sufficient information for the different stages of design. The geotechnical designer should be consulted and contribute to all stages of the investigation. When planning a phase of ground investigation, it is important to consider the needs of all those who will use the data obtained, at a later phase of the scheme.

Geotechnical measurements may be necessary for the purpose of monitoring stability, testing calculation assumptions concerning the ground stability, for the purpose of observing the behaviour of structures and for preserving evidence on adjacent structural works.

It should be appreciated that no ground investigation, however carefully done, ever examines more than a very small proportion of the ground. It is essential that the soil conditions revealed during progress of the excavations are checked to see that they correspond with the geotechnical model, which forms the basis for earth-structure design. It might be necessary to undertake further investigation to determine the extent of anomalous conditions.

5.2.3 Specific geotechnical investigations for earthworks

The design of earthworks needs information on the nature, state, geometry and volumes of soils, rocks and other materials, which will be excavated, dredged, transported, treated, stockpiled, put in layers and compacted. Part of this information is shared with the geotechnical design of the final structure and the main construction phases. Investigations shall cover all zones from which materials can be extracted and the location of final deposits.

The nature of the materials is determined by geological analysis and testing of samples taken from borings, pits or stockpiles. Part 2 of the present standard gives the basis for material identification and the list of parameters and corresponding tests.

The state of the materials is assessed from density and water content measurements *in situ* or in the laboratory.

Geometry and volumes of natural ground layers are based on geological analysis and borings and other *in situ* tests, including geophysical investigations.

For embankment construction, the compaction characteristics of soils are determined by means of laboratory densification and deformation tests (Clause 5). An adequate amount of soil should be recovered to enable testing at a set of water contents, allowing to assess the acceptable range of water content of the material for efficient compaction. Specific studies may then be made for the appropriate treatment of soil material falling outside of this acceptable water content range (Parts 3 and 4 of the standard). When the material cannot be tested in laboratory because of the size of the individual particles or blocks, large test apparatus or *in situ* full scale compaction tests shall be used.

For excavation, information is needed on the ground hardness, which implies the use of different excavation equipment, on the nature and fracturing state of rocks, which control the size of blocks produced by the extraction process and the weathering and evolution of these blocks with time. Such information can be obtained by geological and geophysical analysis of ground masses, including borings and soundings. When relevant, the stiffness and alterability of ground shall be assessed by means of laboratory tests.

For dredging the geotechnical investigation shall cover borrow area and reclamation area, respectively. As dredging often covers large areas, geophysical methods are often included in the geotechnical investigations.

The location and distance of borings and soundings are determined by prior knowledge and by the building object, as well as by the layers and site conditions. If no other indications are available, provision can be made for a distance of approximately 100 m between the direct exploration openings. The depths of the openings should be such that all the layers and groundwater conditions which impact on the earthworks are included. Special situations may necessitate a narrower study grid, as well as other investigation methods.

The investigations regarding earthworks and other structures should be coordinated.

Investigations should include chemical tests of the environmentally-relevant parameters.

5.2.4 *Geotechnical reporting*

The reporting approach shall follow the rules given in the EN 1997 series. These include the preparation of reports at various phases in the ground investigation, design and construction process.

In the geotechnical report, the soils, rocks and other materials and their possible uses shall be presented with the corresponding quantities and their possible interaction with the environment.

5.3 Use of classification systems

The materials used for earthworks shall be classified:

— to enable the planning and specifying construction procedures and quality control methods;

— to ensure the material requirements for earth-structures to achieve the required design requirements of bearing capacity, serviceability and durability.

The main aims of classifications for earthworks are:

1) to sort materials into classes, which have similar properties and behaviour; and

2) to find a prescribed terminology to minimize misunderstandings related to the soils, rocks and other materials when geotechnical reports and other documents are exchanged between different persons.

The classifications for earthworks should cover the relevant properties of the soils and rocks regarding excavating, transport, deposition and compaction.

Part 2 of this standard gives rules for the description and classification of soils and rocks and other materials used for earthworks.

NOTE Due to the variable subsoil and climate conditions within Europe and to the different national contract conditions, national sets of rules have been established in several European countries which could not be harmonized within short period by a European Standard. This European Standard gives therefore basic rules to reach the aims described above. Informative Annexes C to H of Part 1 give examples of national practices following these rules.

Part 2 defines three stages of classification:

— description based on observation: this will yield information on material types, their geometry and position in the ground mass, their variability, etc.;

— classification by parameters of “intrinsic properties”, which are material properties independent from the state conditions during construction e.g. grain size, gradation or plasticity laboratory tests are used to sort the materials into groups with similar properties, e.g. behaviour in an earth structure after compaction. Groups should be used for client specification;

— classification based on parameters of “state properties” additionally, e.g. water content, density, cohesion, strength: for characterization of the workability of materials for execution of earthworks. The corresponding classes may be linked to specific execution processes including excavation, transport, treatment, placing and compaction or to use in earth-structure elements (fill, capping layer, etc.).

As indicated in Clause 6, of this European Standard (Part 1), design of earthworks is based either on experience or on preliminary full-scale tests.

Experience can be used in two ways:

— for simple works, identification of the nature of ground may be considered as sufficient to apply known earthworks techniques;

— for more complex works, testing and use of a more elaborated classification system is necessary in order to choose the best construction process.

Preliminary full-scale tests are used for testing new materials or equipment or when better procedures are expected than the existing ones. They do not use elaborated classification systems, but need the description of ground mass and the identification of materials to enable their description.

The standards for tests that should be used for identification and classification are listed in part 2. These test standards should be used preferably.

6 Design of earthworks for embankments

6.1 Introduction

The earthworks project specifies the execution procedures (strategy for excavation, transport and use of extracted ground or by products, equipment for extraction, transport, spreading in layers and compaction, process adapted to each fill material, quality control) in order to achieve results conform to the requirements (or assumptions) of the earth-structures project.

Since earthworks are frequently controlled using density of the compacted fill, there is a need to link density to the mechanical properties of the resulting embankment, in terms of stability (i.e. shear resistance), deformations (i.e. deformability) and water tightness (i.e. permeability). Durability and long-term stability of the completed body of fill material should be explicitly considered when defining the density requirements.

The design process will thus normally include:

— assessing the nature and material properties of available soils, rocks, by-products or recycled materials;

— assessing the required properties of the compacted fill materials and how these can be achieved;

— defining the construction process while considering the type of work (excavation, compaction, etc.), the available equipment, the nature and initial state of the soil/rock, the climate, and the desired final state;

— optimising the earthworks project in terms of equipment use, limitation of transport, protection of the environment, sustainable development, cost, duration of works, etc.;

— identifying the appropriate form of validation of the works (testing and monitoring method and frequency of testing during construction) (prEN 16907-5).

For embankments, the compaction procedure (number and thickness of layers, compaction equipment and energy) depends on the available fill material, on the climatic conditions, and on the required final properties of the completed embankment. It may require improvement of the fill material by various techniques (aeration, humidification, mixing with other materials, use of binders).

Because of the difficulty of extrapolating from laboratory tests the optimum construction procedure for a given site, full-scale compaction trials are a valuable reference tool to assess the efficiency of each possible technique. The experience gained from these tests and earthworks projects over years has been synthesized in “classifications” (prEN 16907-2), which help earthworks designers to select the construction procedure. The use of such classifications is considered as one of the ways to apply the present standard.

Earthworks are a complex mechanical process which cannot be modelled to reflect all the complexities of the construction process. Therefore the engineering approach is to use a mix of laboratory testing and full-scale compaction trials including *in situ* testing. In the case of rock fill, laboratory and compaction tests are even more difficult and design decisions are almost entirely based on engineering judgement and experience for the particular sources of rock fill material.

6.2 Design procedure

6.2.1 General

In this European Standard, the collective term "embankment" is used to describe any earth-structure formed by the placement of engineered fill. The term embankment therefore covers the construction of raised earth-structures (traditionally described as embankments), the infilling of large excavations such as disused quarries, and earth-structures formed by dredging.

Embankments are built by recognized earthworks methods in order to meet a prescribed behaviour, in terms of resistance, deformability, permeability and durability:

a) spreading and then compacting layers of fill material (prEN 16907-3 and -4)

b) placement of coarse granular material such as boulders (prEN 16907-3)

c) hydraulic placement of fill (prEN 16907-6 and -7)

In the cases of a) and b) above, the properties of the completed embankment may be obtained by dividing the embankment into zones (6.2.2), with different requirements for each zone. The specifications for each zone are part of the earth structure project. The earthworks project defines the best way to meet these specifications.

6.2.2 Embankment zones

6.2.2.1 General

The cross section of an embankment can be either homogeneous, or divided into different zones, when needed. Each zone shall then be defined in terms geometry and of quality, density and other mechanical, physical and chemical properties of the compacted material.

6.2.2.2 Infrastructure embankments

The cross-section of infrastructure embankments (for highways, railways, waterways, flood defence, dykes or dams) may be divided into the following zones (see Figure 1):

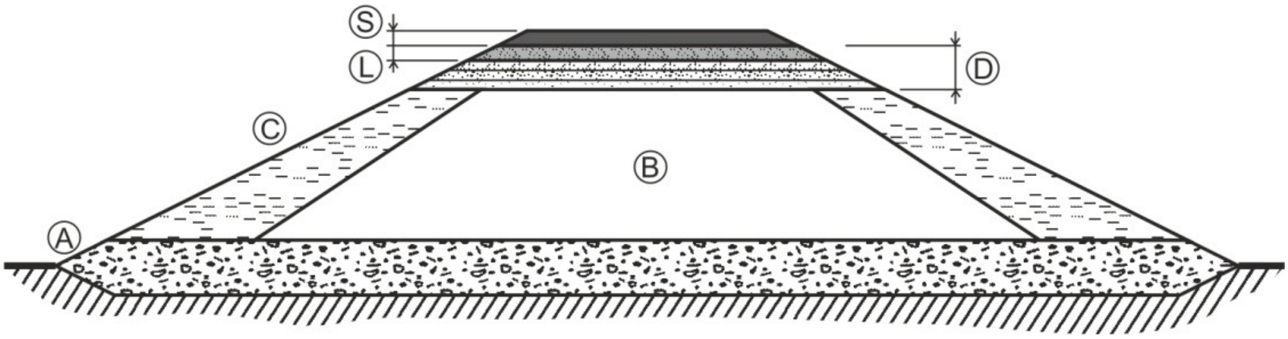
— **Base** (A): Embankment zone in direct contact with the existing ground. This zone may be divided into layers, e.g. for drainage, working platform, impervious protection layer. It may include replacement of existing foundation ground to some depth or improvement of existing ground by binders or installation of geosynthetics.

— **Core** (B): Embankment zone located between any base layers and upper zone. To make this zone exist, a minimum embankment height is needed. The core can be protected from water or isolated to limit pollution of the environment.

— **Shoulders** (C): lateral zones of embankments. These zones can have various functions, e.g.: enable steeper slopes, protect the core, serve as filters, protect from erosion.

— **Upper zone** (D): zone located between the core and the superstructure (pavement, track). This zone may comprise different layers such as the "upper part of fill", the "capping layer", a "transition layer" to separate rock fill from the upper granular layers, an impermeable layer, etc. It does not include the superstructure layers.

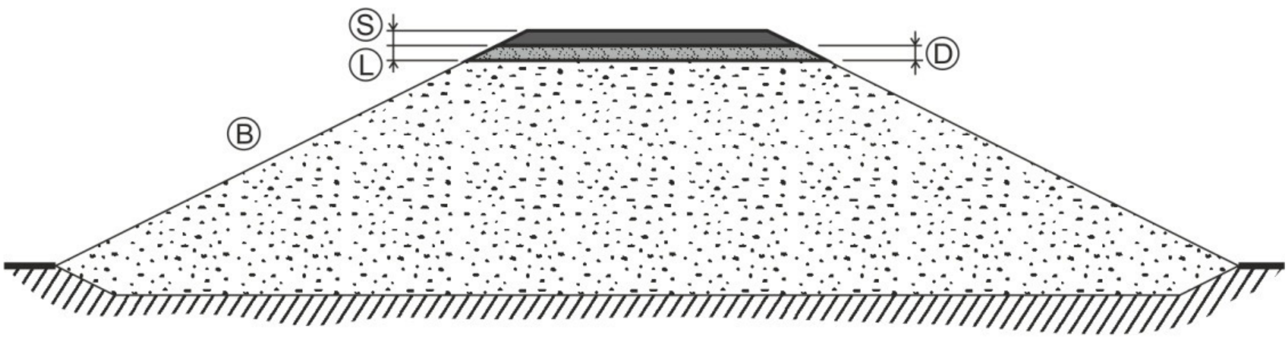
The materials in zones A, B, C and D may be the same (Figure 2).



Key

A — base
B — core
C — shoulders
D — upper zone
L — capping layer (part of upper zone)
S — superstructure (pavement /rail track)

Figure 1 — Zones of infrastructure embankment: general case



Key

B — core;
D — upper zone;
L — capping layer (part of upper zone);
S — superstructure (pavement /rail track)

Figure 2 — Zones of a homogeneous infrastructure embankment

The dimensions of the different zones and the properties of their materials shall be selected to fulfil the requirements of the global civil engineering project. The civil engineering project defines the required behaviour of the final earth-structure in terms of deformability, stability, bearing resistance, permeability and durability. The present standard assumes that the functions of each zone have been decided with due account for the possibilities offered by the materials available on site.

The design of the different zones shall consider all aspects relevant to the project including the following:

— the potential for settlement below, or changes in volume within, the embankment post construction;

— materials sensitive to water should be protected;

— polluted materials should be insulated to avoid leaching of pollutants;

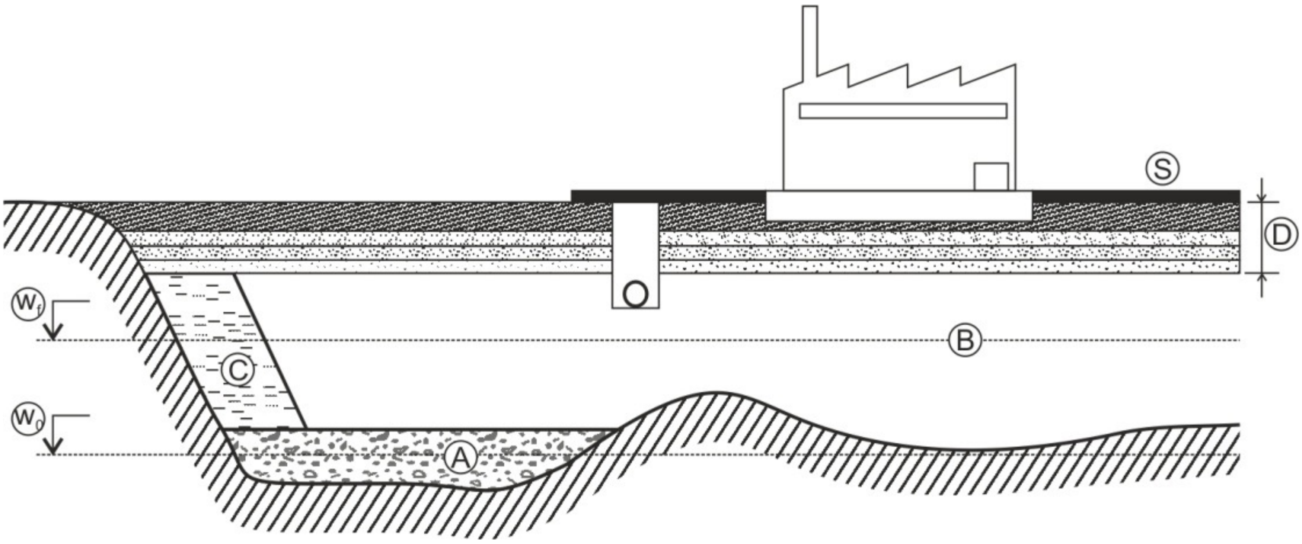
— materials sensitive to the chemical properties of the underlying soil should not be in contact with it (foundation layer);

— the geometry of the zones shall account for the construction procedure (core and side zones).

6.2.2.3 Filling large excavations and natural depressions

Embankments used for filling a large excavation or depression may be divided using the same zones as for infrastructure embankments (Figure 3). In addition to the precautions listed in paragraph 6.2.2.2, the eventual presence of a varying water table shall be considered when designing these earthworks.

The earth-structure designer should consider that: where a significant thickness of fill is placed over a wide area the load due to the fill can often result in substantial settlement, both self-weight settlement and settlement of the underlying ground. Furthermore, at some time after construction the earthwork may suffer collapse compression upon inundation with water if the engineered fill has a high air-voids content, (particularly where fill is placed below the long-term groundwater level). In case of loose uniform sand filling the excavation with high water table, the danger of liquefaction shall also be taken into consideration. These potential causes of ground movement should be considered in the design of earthworks to fill excavations and natural depressions. The designer should consider the required properties of the fill material both in terms of the required bearing capacity of any overlying structures, and to limit ground movements related to those structures. This may necessitate setting compaction requirements in excess of what is normally required for infrastructure embankment fill material, and in some cases limiting the types of fill material that can be utilized, in order to limit movement within the body of the earthwork itself.



Key

A — base

B — core

C — shoulders

D — upper zone

S — superstructure

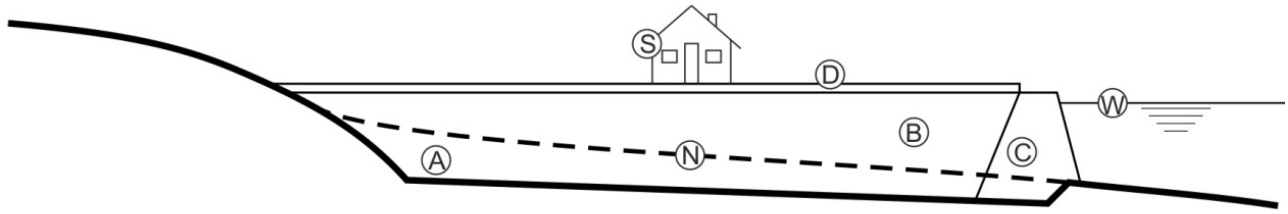
W_0 — water table at the beginning of works

W_f — water table at the end of works

Figure 3 — Zones of embankment in excavation or depression: general case

6.2.2.4 Land reclamation by dredged hydraulic fill

Land reclamations created by hydraulic placement of dredged material are usually divided into zones similar to those of paragraphs 6.2.2.2 and 6.2.2.3 (Figure 4). The core is the main zone of such fills. The base consists of the natural sea, lake or river bottom ground, which is cleaned when needed to eliminate compressible deposits. Lateral bund structures or dykes limit the extent of filling, prevent spill of hydraulic fill into the environment and enable construction of steeper slopes. The upper zone contains all the transition layers to the superstructure.



Key

A: base (hydraulic fill after dredging to remove compressible soils);

B: core (hydraulic fill);

C: bund (dyke);

D: upper zone;

N: original ground level prior to dredging;

S: superstructure

Figure 4 — Zones of hydraulic fill for land reclamation

The civil engineering project defines the required behaviour of the final earth-structure. The present standard assumes that it was designed with due account of the fill materials available. The execution of hydraulic fills with dredged materials shall consider:

— the existence of fine fractions which may or may not be freely spilled into the water environment;

— the need to isolate polluted materials to avoid leaching of pollutants;

— the geometry of the dredged and filled zones.

The possibility to obtain the required final properties of the embankment may depend on ground improvement techniques, which are not covered by this European Standard.

6.2.2.5 Buildings and structures on fill

The designer shall consider the nature of each earth-structure and the intended use; where buildings and structures are to be constructed on or within the earth-structure then particular consideration shall be given to the sensitivity to total and differential settlements. The earthworks designer shall consider all aspects that could impact on structures to be formed on or within the embankment, including:

- settlement of shallow foundations;
- negative skin friction on piles or shafts through the embankment; and
- lateral pressure due to compaction on immediately adjacent structures (such as bridge abutments and retaining walls).

Consideration should be given to the acceptable magnitude of self-weight settlement within the body of fill material during and after construction (including the risk of collapse on inundation by water described in 6.2.2.3). Beneath areas of the earth-structure where there are strict settlement tolerances then the designer shall give careful consideration to: the depth of fill material, permissible fill materials to be utilized, the compaction effort to be applied to those fill materials and the required final properties of the fill material.

The required properties of the fill material should be considered in terms of the density and air voids of the compacted fill, as well as the stiffness of the fill immediately after compaction. The required stiffness will often necessitate achieving a higher overall degree of compaction than for a traditional infrastructure embankment, which will favour placing the fill at a relatively low water content. However, the earthworks designer should ensure that the water content at the time of placement and the compaction effort required are sufficient to ensure that the compacted fill avoids unacceptable post construction changes (6.3.3).

6.3 Selection of the fill material properties and compaction process

6.3.1 General

The earthworks fill material design involves the identification of fill material that is suitable for the construction of an earthwork, and determination of the appropriate fill material properties and compaction process to ensure that the requirements of the completed earth structure can be satisfied. Clause 6.3.3 describes the issues that need to be addressed when undertaking the earthworks fill material design.

For economic, environmental and practical reasons, the fill materials used to construct an earthwork are usually those available to be won from the cuttings or borrow pit excavations either on or close to the site of the project. It may be necessary to treat or modify the excavated material to ensure that it is suitable for use. When the project requires fill materials with specific properties that are not available on the site, then the project will need to import fill material. In each of these cases, the earthworks Designer shall assess the fill material to determine whether the required fill properties can be satisfied subject to an appropriate placement and compaction process.

Fill materials are initially assessed as being potentially suitable for use in earthworks based on intrinsic classification properties of grading, plasticity index, chemistry, etc. The design process of selecting the acceptable range of material properties for a given fill material is then undertaken based on laboratory compaction test results (except for fills that are too coarse for tests to be performed). For soil fills, the acceptable material properties commonly relate to either water content or shear strength (or an earthworks test that relates to these properties).

The overall earthworks fill design process involves the identification of a way to use the available natural or recycled materials to place fill material to meet the requirements of the earth-structure. The success of this process depends on various activities: material assessment, definition of the earthworks Specification, selection of construction equipment, selection of the construction process, and quality control during construction. These activities can be undertaken by different organisations (client, engineer and contractor) on a single project, in which case there should be clarity about who is leading on each aspect since all are having some influence on the earthworks design. This standard applies to all parties who are involved in the earthworks fill design process. The identification of appropriate fill properties and construction process should be assessed during the preparation stage of the project (i.e. prior to commencement of earthworks construction), but the nature of earthworks projects commonly dictates that the design will need to be adjusted during the construction phase to address natural variation of materials encountered. Consequently, further details on design related aspects are provided within prEN 16907-3, -4, -5, -6 and -7, because earthworks design continues through execution.

This design process can be considered as an overall system that requires input by various project participants, and involves the following three common stages of activity (references to parts of the prEN 16907 series that relate to each item are shown in brackets):

Common Fill Design Stage 1 – assessment of the materials available, which includes:

- soil and rock classification of material that will be generated from cuttings (prEN 16907-2);
- identification of other potential sources (borrow pits and imported fills) and classification of the materials (prEN 16907-2).

Common Fill Design Stage 2 – assessment of the fill behaviour and the limitations to be placed on use of each fill material, which includes:

- identification of the criteria to be satisfied to deliver the required earth-structure performance;
- classification of the available soils, rocks and recycled materials as classes of fill material (prEN 16907-2 or prEN 16907-1, informative annexes practice C to H);
- assessment of the compaction behaviour of the fill materials (prEN 16907-1, -3, -4, -6 and -7);
- identification of the acceptable water content and density range to satisfy the required earth-structure performance criteria (prEN 16907-1);
- set the earthworks Specification requirements for the project (prEN 16907-1).

Common Fill Design Stage 3 – selection of appropriate controls for the earthworks construction, which includes:

- consideration of the most suitable construction methods and equipment (see prEN 16907-3, -4, -6, and -7);
- identification of the most appropriate form of quality control / quality assurance (prEN 16907-5);
- confirmation of the adequacy of the fill design by a site trial or testing of the works, and clarification if necessary (prEN 16907-1).

National practices across Europe do not explicitly separate activities into the three design stages summarized above, however review of those practices shows that each of the stages is satisfied in some form under each of the different national practices. Therefore, it is considered reasonable to summarize that the earthworks design process should address each of these common fill design stages. On many projects, a different assessment will be made for different earth structures or zones of an earth structure.

6.3.2 Characterization of materials

The identification and characterization of materials available for use as fill is the first step of all procedures for earthworks design. Identification involves the characterization of the nature of soils and rocks. This will include some of the following intrinsic properties: grain size distribution, water content, carbonates, sulphates, organic matter contents, plasticity and liquidity limits, methylene blue value for soils, Los Angeles coefficient, dynamic fragmentation, friability, degradability, fragmentability, frost resistance for rocks, and specific tests for other materials. This information is used to classify the materials (prEN 16907-2).

6.3.3 Criteria for assessing the compacted fill material

The requirements to be satisfied by the earth-structure are identified either by the client or as an output of the geotechnical or structural design. For example, this might result in a required end performance related to stiffness at finished ground level and limitations on permitted settlement beneath a defined loaded area.

The earthworks design should identify the earthworks criteria that are to be satisfied in order to deliver the earth-structure requirements (such as stiffness) and to avoid problems both during and after construction. These criteria will vary depending on the particular site conditions, fill materials available and end use of the embankment, and may include some or all of the following:

— criteria relative to the completed embankment:

 — minimum value of the vertical deformation modulus;

 — minimum value of the bearing resistance;

 — maximum or minimum value of the permeability, when required;

— criteria relative to construction phases:

 — trafficability (for ease of execution);

 — no mattressing or separation of layers or cracking due to desiccation (for quality of compaction/method of working);

— criteria relative to durability:

 — long-term stability of the compacted fill, especially resistance to water content changes (no collapse, no heave, no settlement);

 — frost resistance;

 — degradability.

The above requirements shall be transformed into requirements put on potential fill materials and construction process (compaction procedure and eventual treatment of materials).

In most cases, the compactability of the potential fill materials is assessed first, using standardised laboratory compaction tests when they can be performed (typical exceptions are fill made of blocks or very coarse materials). The designer shall make assessments recognizing that laboratory compaction test results are only an indicator of a fill's response to a standard compactive effort. It can be advantageous to undertake both standard and modified Proctor tests to clarify the response of the material to variation of compactive effort. The mechanical properties and durability of the compacted fill material within the embankment, for a given compaction process, should be checked by full-scale compaction trials or *in situ* testing of the early layers of the embankment (for density, stiffness, deformability, resistance or permeability measurements). This can be done for a given earthworks project or organized at national or international scale, to prepare experience-based rules, which can be used at the design stage or for current works.

These tests or experience-based rules are the condition to recommend the use of dry density, when applicable, to specify the desired state of the fill material after compaction.

6.3.4 Compaction behaviour of fill materials

The assessment of the compactability of each available fill material is the next step of the procedure. When the fill material behaviour depends mainly on fine soils, it shall be tested in the laboratory. In all other cases, full-scale compaction trials (Annex A) are recommended. The laboratory compaction tests shall be undertaken on soils proposed for use as fill to identify the dry density that is likely to be achieved when a soil at a given water content is compacted by a standard compactive effort. Samples of the soil are tested over a range of water contents to determine the maximum dry density and optimum water content for the applied compactive effort. For soil fill materials, two test procedures are most commonly used, the standard Proctor and modified Proctor tests, which differ by the applied compaction energy.

The selection of the test procedure depends on the nature and the state of the soil, and the anticipated level of compactive effort that will be applied on site. It may be defined at national or regional or project level.

Example results for standard and modified Proctor laboratory tests on a single soil type are illustrated at Figure 5. The higher compactive effort of the modified Proctor test results in a lower optimum water content and a higher maximum dry density; the notable exception being for uniformly graded sand or fine gravel where the increase in compactive effort has limited effect.

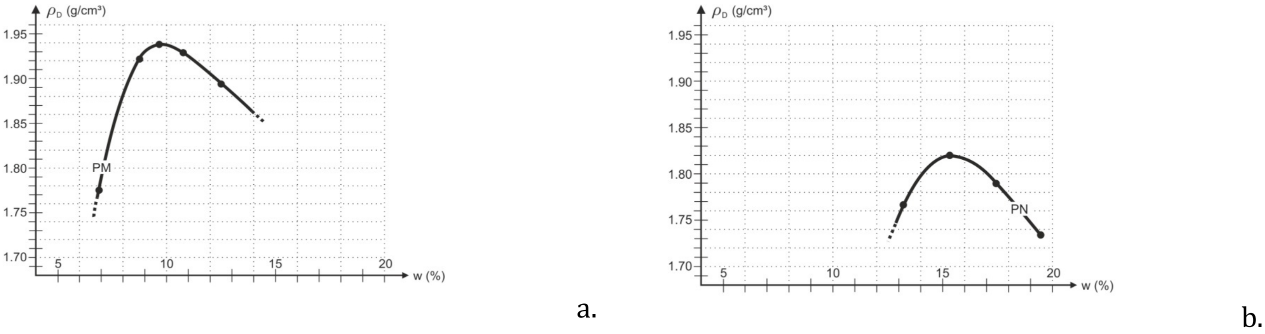


Figure 5 — Examples of (a) standard and (b) modified Proctor curve test results

When both tests are undertaken on a particular soil type, the earthworks designer should plot the laboratory test result data on a common graph to help with the assessment of the appropriate range of water content for fill compaction and the target dry density that should be achieved by compaction on site.

The state of the fill material should be clarified by plotting the air voids content or the degree of saturation lines for the fill. This requires the specific gravity of the material to be identified, either by laboratory testing or based on a reliable estimate for a known material type.

The water content of a soil at the time of excavation, or of a fill at the time of placement, will often differ from optimum water content. Furthermore, water contents may vary inside a soil layer and change between studies and construction works, because of seasonal climatic changes. Therefore, the characterization of soil compactability shall include an assessment of the admissible water content range and corresponding dry densities and mechanical behaviour and durability. The acceptable range of water content can be defined based on a lower and upper acceptability limit as indicated in Figure 6.

Many fill materials compacted noticeably dry of optimum water content with a high air voids content are susceptible to post compaction changes in volume in response to changes in water content. The likely post compaction behaviour depends on various factors, including: fill grading, water content at time of placement relative to optimum water content, plasticity, mineralogy, overburden pressure within the finished earth-structure, and for fills comprising lumps of clay, the degree of overconsolidation. The factors relevant to the particular soil should be identified, and the potential for post compaction changes assessed by the designer.

The objective of the earthworks fill design is to define a zone of accepted water content that produces a satisfactory densification (Figure 6). Criteria are commonly defined relative to minimum acceptable final density, often in combination with maximum acceptable final air void ratio (or degree of saturation), plus lower and upper acceptable water content values in order to achieve acceptable mechanical properties and to minimize post compaction changes. The criteria identified enable the earthworks Specification to be prepared (see Clause 12).

Coarse (granular) fill materials are relatively easy to assess, see Figure 6a:

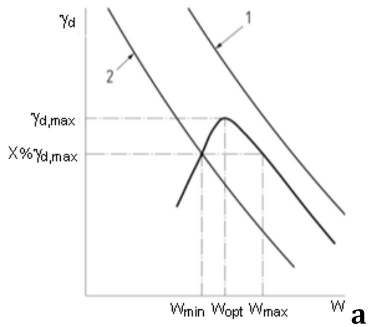
- Upper acceptable limit – normally defined based on a required percentage of the maximum dry density, and consideration may also need to be given to the potential for over-compaction resulting in excess porewater pressures and mattressing.

- Lower acceptable limit – a check shall be made of whether the density criteria needs to be further restricted based on air voids to avoid long-term risk of collapse settlement.

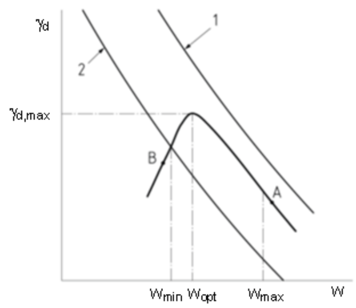
For fine (cohesive) fill materials (Figure 6b) the designer should give particular consideration to the following when assessing acceptability limits relating to water content:

- Upper acceptable limit – designer shall consider the required strength/stiffness of the compacted fill, and also the minimum fill strength that will permit construction and avoid creation of excess porewater pressures due to compaction (e.g. a fill at point A on Figure 5X5b will not benefit from further compaction).

- Lower acceptable limit - shall be selected giving consideration to air voids (or degree of saturation) to minimize the potential for excessive movement post construction (e.g. a fill at point B on Figure 6b will have a high air voids ratio and additional compactive effort is required to increase the fill density in order to achieve a stable fill).



a.



b.

Key

1 Saturation line (0 % air voids)

2 a% air voids line

W water content (%)

γ_d dry unit weight (kN/m^3)

w_{opt} optimum water content

w_{min} lower acceptability limit

w_{max} upper acceptability limit

Figure 6 — Examples to illustrate the definition of a water content range based on compaction curve (a) coarse soils (b) fine soils

Where a fill material that is well understood based on past practice, is to be used within an earthwork setting that has well-established precedent, the design assessment can be based on laboratory testing relating to characterization and compaction test results. In this situation, the design can be developed based on established national practice and experience; where possible utilizing empirical correlations of soil index properties to mechanical properties such as likely strength or stiffness of the compacted fill. However, where the fill will be used outside of the well understood range of experience, then the behaviour of the fill should be clarified by laboratory relationship testing (see 6.3.5).

Specific information on how these issues are addressed for practical types of fill material, and similar examples based on saturation lines, are included within prEN 16907-3 and Annexes B to H describing national practice.

6.3.5 Relationship testing to assess fill performance

The information revealed by the compaction test for the particular fill material can be related to the mechanical properties of the compacted fill by undertaking additional laboratory tests on each of the compacted samples, a process known as “relationship testing”. By this approach, the relationship between water content of the placed fill and the strength/stiffness or permeability of the compacted material can be determined. Relationship testing can be extended to assess the potential changes in strength/stiffness and volume of compacted fill samples as a result of increase in water content post compaction, this can be assessed by undertaking soaked CBR tests.

The results from various laboratory tests undertaken should be collectively plotted by the earthworks designer to enable determination of the appropriate range of fill water content and dry density that will enable the compacted fill to satisfy the required geotechnical design properties for the finished earth-structure (or identify whether the particular fill material is not suitable for the particular end use). This process completes the laboratory assessment of the potential fill material and enables the designer to develop the earthworks Specification.

The relationship testing process requires the recovery of a number of bulk samples of the fill to be recovered during the ground investigation to ensure that sufficient material is available for testing.

6.3.6 Link between construction method and earthworks fill design

The earthworks construction equipment to be used on the project for excavation, treatment, placement and compaction of the fill material should be selected allowing for the type of fill to be placed and the site conditions to ensure that the compaction requirements can be satisfied.

The suitability of a given equipment to adequately compact a given fill should reflect previous experience, and can be confirmed by means of full-scale compaction trials using the selected soil or rock fill and the selected compaction equipment. These tests should be made in advance of or at the beginning of the main works and can be incorporated into the works if shown to be acceptable.

It is good practice during construction to confirm that the fill material design and proposed construction procedure are appropriate. This should be done by review of *in situ* test results on the fill placed and compacted at the start of each relevant phase of earthworks (e.g. first use of a given fill material or construction process). If there is a clear discrepancy between the *in situ* test results achieved and the design target then an assessment should be made of whether the problem is with the construction method or the design target. On some occasions, it proves to be necessary to modify the design to reflect the materials available because earthworks design is an iterative process.

6.3.7 Validation of the compaction process for a given fill material

The appropriate form of compliance testing to be implemented on site to control the earthworks should be selected at the design stage of the project. It should consider the feasibility of performing compliance testing relative to the selected acceptability criteria and the constraints imposed by the contract and construction operations (see prEN 16907-5 for details).

The quality control system validates the compaction process relative to the design by reviewing the following elements:

— the initial state of the fill material;

— the degree of variation of the fill material properties;

— any modifications which will be applied to this material before compaction;

— the layer thickness;

— the compaction equipment used (principle, weight, speed, vibration);

— any compliance testing of placed fill material to enable confirmation of achieving any end product QA requirement;

— the number of compaction passes applied to the material;

— the verification of the results.

Each of these elements shall be recorded in order to associate the assessment of the resulting compacted material (using the criteria of 6.3.3) to a defined compaction process.

NOTE Informative Annex A details an example of procedure used to validate a compaction process, including the necessary information on the material and the modifications to which it was submitted, the procedure for creating a layer, the size of the test zone, the thickness of the layer, the equipment used for compaction, the way compaction was executed, what has been checked, the criteria used for assessing the results and the content of the report.

The process for correctly compacting the fill material should be selected from the results of these tests. The allowed variations from the tested material should be determined, in order to guide the works in case of variations of the ground or other materials used for making the embankment.

Local experience may be used to extrapolate the test results, or even replace the tests, in case the same soils or rocks or other materials have previously been used for the same type of work.

6.3.8 Design of embankment cross-section

The design of the cross-section is part of the earth-structure project. It shall account for the required properties of the embankment and the available materials. As mentioned in 6.2.2.2, care should be taken of protecting water sensitive materials, avoiding leaching of polluted materials and contacts between reactive materials

NOTE Examples of typical embankment cross-sections are given in 6.2.1.

6.4 Design of specific parts of embankments

6.4.1 Introduction

Special design and construction requirements apply to some earth-structures or some site conditions, in addition to the general ones described in this European Standard. They can appear simultaneously. The most frequent ones are considered below.

6.4.2 Capping layers

The capping layer is a transition layer, which can be placed between the top of a fill or the base of an excavation (subgrade) and the overlying infrastructure (road, railway). This intended function necessitates the use of an appropriate quality of fill material. The upper surface of the capping layer is the “platform” or formation.

Capping layers are installed to fulfil two series of functions, when needed:

During the construction works (Short-term functions)

— accurately levelling the platform, in order to facilitate the execution of the superstructure;

— offering sufficient stiffness or bearing capacity, despite weather variations, for a correct execution of compaction of layers or structures above (« anvil » effect);

— protecting the subgrade of the fill or cut, from weather effects;

— assuring good traffic conditions for the equipment needed for building the superstructure;

— eventually, supporting construction traffic for other purposes.

For some types of capping layers, temporary or permanent traffic restrictions may need to be stipulated.

After the end of construction (Long term functions)

— homogenizing the deformability of the fill or excavation base, as specified by the design of the superstructure (definition of characteristic and/or minimum values);

— assuring minimum stiffness, which is constant over time, despite fluctuations in moisture conditions of underlying water sensitive materials, and can be estimated with sufficient accuracy for the design of the superstructure;

— improving the bearing capacity of the platform to optimize the combined cost of the “capping layer/superstructure” system;

— offering a thermal protection to frost sensitive soils/materials;

— contributing to the drainage of the completed structure.

Depending on the site conditions (soil type, climate, hydrogeological environment, traffic ...), the capping layer may take different forms. It can be:

— reduced or non-existent when the materials of the embankment or the cutting have the required properties;

— limited to a single layer of material having the necessary characteristics;

— made of superimposed layers of different materials having different functions, including for example a geotextile, a coarse material layer, a layer of fine adjustment, a gravel coating, a binder improved soil... Such a combination of individual layers may be designed to form a capping layer with adequate properties.

6.4.3 Transition zones

6.4.3.1 Introduction

Embankments may comprise different types of transition zones: longitudinal transitions for half cut/half fill sections, transitions from embankments to cuts, transitions from embankment to structures, interactions with other earth-structures replacing usual lateral slopes, interactions with culverts or other structures crossing the embankment core.

All transition zones require specific design, in order to provide adequate changes in stiffness and permeability, solutions to drainage problems, or other requirements depending on the type of infrastructure.

6.4.3.2 Half fill/half cut profiles

This type of transition takes place when a cross section is made of two different parts: fill and cut, (see Annex B for an example and appropriate terminology). The profile continues along the infrastructure, roughly showing the intersection between fill and natural ground, until a full cut or fill section is obtained.

The design of this earth-structure involves the evaluation of stability according to EN 1997-1, and a specific design to provide indentation among both types of profile. Most typical designs include steps in the natural ground (and provide its drainage) and zoning of the embankment section.

Proper drainage at the cut-fill contact should be considered.

6.4.3.3 Transition from embankment to cut

Transitions from embankments to cuts are special earth-structures which should be designed to avoid sudden changes in stiffness from the bottom of the cut to the top of the embankment.

Transitions in which the succession is downslope, from cut to embankment, shall be designed in order to avoid the entrance of run-off water to the top of the embankment through its upper layers due to its direct contact with the bottom of the cut, which can lead the runoff from itself, slopes and adjacent areas. Thus some transversal trenches or other specific drainage designs should be generally projected, unless the expected runoffs were too small.

6.4.3.4 Transition from embankment to structure

On the transition between earthworks and structures (e.g. bridges), suitable measures should be taken both to reduce differential settlement and to ensure that there is a gradual transition of support stiffness.

On defining the transition zone, the following aspects should be taken into account:

- the type of structure abutment (open, closed, underpass, frame, piled, etc.);
- the construction process;
- the height of the embankment;
- the stiffness and strength of the subsoil.

The following aspects should be considered:

- special care should be taken in the compaction works, mainly in the vicinity of the structure and in open abutments;
- selected compactable backfill material like well graded sand and gravel or crushed stone should be used;
- for fine soil, treatment by binders should be considered to improve stiffness (See prEN 16907-4);
- deep soil mixing can be used alternatively to enhance the stiffness of the transition zone;
- transition slabs can also be designed;
- a drainage layer shall be incorporated behind the structure;
- lightweight fill (fly ash, expanded clay aggregates, EPS blocks, etc.) may be used to reduce settlement and lateral earth pressure.

6.4.3.5 Special lateral structures

One or both lateral zones of a fill may be replaced by special structures, for specific purposes, such as protection against floods and erosion, steeper slopes. The existence of these zones is part of the earth-structure project. They may interfere with the execution of the earthworks.

6.4.3.6 Interaction with structures crossing the embankment

Different approaches can be adopted, depending on the dimensions and depth of undercrossing structure below the superstructure, and the changes in stiffness linked to the presence of the undercrossing. The deeper the undercrossing structure is, the lesser is its influence on the superstructure.

- Deep undercrossing structures: The relative changes in stiffness range from:
  - vertically: from the top of the undercrossing structure to superstructure;
  - horizontally: from the top of undercrossing structure to both sides.
- The vertical transition in stiffness, by means of one or different layers, should provide homogeneous bearing conditions for superstructure above.
- Shallow undercrossing structures: If vertical changes in stiffness are not able to provide homogeneous bearing conditions for the superstructure above; the undercrossing structure can either be buried or not. As a first approach, the problem should be focused under a close point of view to that of transition from embankment to structure (see 5.7.4.4), by means of specific design from the sides of structure, but also from its top when buried.

6.4.4 Embankments on slopes

This type of section takes place when the cross section of the earth-structure is made of an embankment founded on a slope, directly on the natural ground.

The design of this earth-structure involves the evaluation of stability according to EN 1997-1, and a specific design to provide the indentation of the embankment in the ground. Most typical designs include steps in the slope (natural ground), provide its drainage and define zoning of the embankment section. Drainage of the slope above the embankment and possibly soil replacement by granular material under the toe are most important.

6.4.5 Specific materials

The design of embankments built of some types of materials, requires specific prescriptions, going beyond those which are common and considered valid in most general cases.

The first stage is the knowledge of relevant long-term properties of these materials, and their influence on the predictable behaviour of the earth-structure. These materials can be either natural soils, by-products or waste of industrial or mining processes, or even specific man made materials. From this point of view, some of the general rules and principles included in this standard can be applied in a different way or even become inapplicable. Usually, specific rules concerning health, environmental and other sectorial aspects have to be taken into account.

The general framework for the specific materials used for building earth-structures shall be acceptable in terms of:

— health;

— environmental issues;

— bearing capacity and long term behaviour, according to the purposes of earth-structure;

— constructibility.

This section only provides information about natural soils and rock, which require specific design when used for earth-structures, but not about every specific waste, by-product, or manmade material.

The main types of natural soils and rocks demanding specific prescription for earthworks purposes are:

— swelling soils (see prEN 16907-3:2015, Annex E);

— chalk (see prEN 16907-2:2015, Annex A, Clause A.5),

— arid soils (see prEN 16907-3:2015, Annex A, Clause A.6),

— tropical residual soils (see prEN 16907-3:2015, Annex A, Clause A.7),

— soils containing soluble salts (see prEN 16907-2:2015, Annex A, Clause A.8),

— permafrost (see prEN 16907-3:2015, Annex A, Clause A.9)

— soft soils (see prEN 16907-3).

Generally, these are:

— materials with particular constituents;

— very dry or very wet materials;

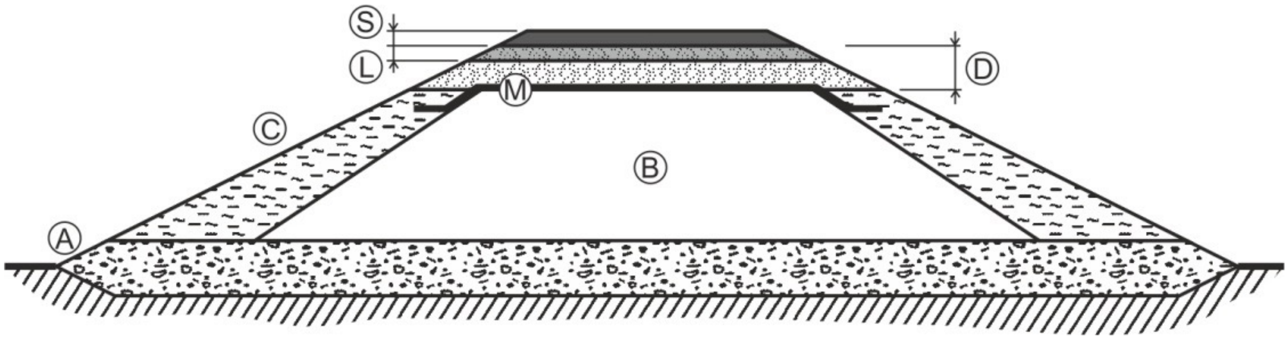
— very clayey materials;

— homometric or poorly structured materials;

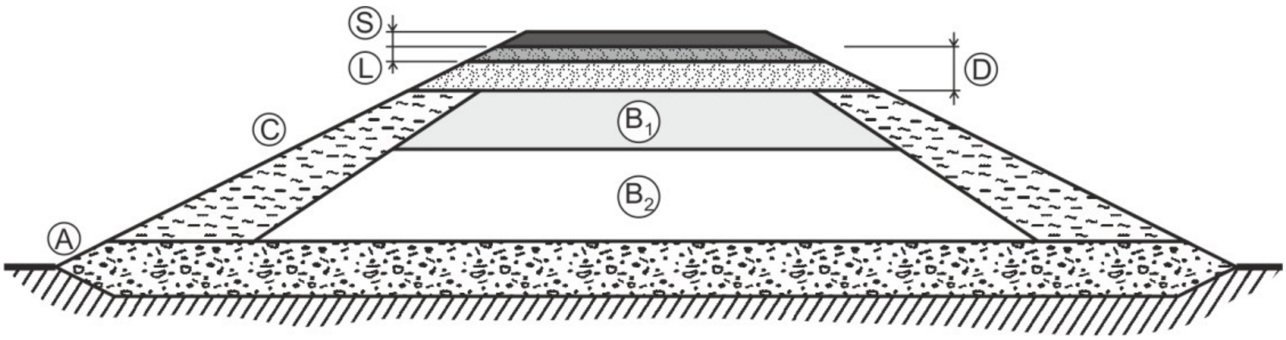
— materials which are changeable or fragmentable (brittle).

In addition to geotechnical laboratory and *in situ* testing and data collection, local experience in design and knowledge of geological nature and conditions shall be taken into account.

Examples of embankments of the core which is made of marginal materials are shown in Figure 7.



a.



b.

Key

A — foundation

B — core (marginal material sensitive to water action)

B_1 — upper part of core made of non marginal material (usually clayey soil) isolating B_2 from upper infiltration and providing weight if B_2 is a swelling soil

B2 — marginal material (sensitive to water action)

C — impervious shoulder (e.g. clay or clay+lime)

D — upper layers

L — capping layer

M — impervious manmade sheet

S — superstructure

Figure 7 — Two examples of use of marginal materials in a road or railway embankment

6.4.6 High embankments

High embankments (e.g. height exceeds 15 m) may require special studies for compaction of the soil. Weak soils and rocks, and those that are prone to degradation post construction, should be avoided for the construction of high embankments, and when used this should only be under strict design prescriptions. High embankments shall have their stability checked by a soil mechanics type of approach. Deformability of the embankment foundation soil shall be checked in addition.

The self-settlement of high embankments, which is often assumed between 0,5 % (good conditions like compactable coarse soils) and 1 % (for bad conditions, fine soils with high water content) of the height, should be controlled. The self-settlement can be reduced by higher grade of compaction or improvement of the soil with lime and hydraulic binders respectively.

In addition, it may be necessary to include a monitored hold period once the earthworks reach full height and prior to completion of any sensitive elements of the infrastructure upon the earthworks.

6.4.7 Embankments on soft soils

Design of embankments on soft soils shall be done in accordance with EN 1997-1.

When selecting fill materials to form embankments to be placed on soft soils, the earthworks designer shall give consideration to the following:

- potential for flood waters to saturate the embankment fill material. If this is a significant risk, then fill material that is likely to be adversely effected (such as fine grained fill material placed dry of optimum moisture content) should not be utilized below the predicted flood water level;

- the necessity for a granular starter layer to provide a stable platform upon which adequate compaction of subsequent layers of fill material can be achieved. This starter layer should be designed to ensure the stability of the embankment, which may necessitate incorporation of geosynthetic reinforcement, and a geotextile separator may be necessary at the top of the starter layer if it is constructed on coarse uniformly graded granular fill.

- the rate of filling shall be assessed to ensure that excess pore water pressures generated within the soft soil below the embankment can dissipate at a rate that ensures the stability of the embankment during construction. Several phases of embankment construction will eventually be decided.

6.4.8 Embankments built above cavities

Earthworks for embankments construction shall account for the existence and type of the cavities lying under the foundation of embankments. It can be decided that:

— no specific action is needed and the embankment can be founded in the natural ground;

— natural ground has to be dug to a certain depth, and to be substituted or compacted;

— natural ground has to be treated in order to fill cavities or holes;

— manmade cavities or structures have to be repaired or even filled, or some new structures have to be built to allow the presence of the embankment;

— other specific designs have to be adopted (light embankments, piled structures…).

6.4.9 Surplus materials

Excess masses of soil, which cannot be used for purposes like fillings, dams or as aggregates, are commonly placed in areas as landscape fill to improve and limit the environmental impact of the earthwork on the local area, and to avoid off-site disposal. In many cases, these soils are of inferior quality in matters of strength or contamination. Minimum compaction requirements shall be assessed to avoid instability and unacceptable deformations.

Contaminated soils are often fine grained and of low permeability. Thus slightly contaminated soils can be placed in landscape fills on the site, because only a negligible amount of seepage water will spread out. The amount of seepage water can be reduced if the deposit is covered by a sealing of low permeable soil or artificial linings like plastic liners. Final deposits for contaminated soils shall fulfil the national environmental rules.

In the case of dredged soils, dumping sites should be approved and include a drainage, so the mostly wet and soft soil can be dewatered and eventually reused (see prEN 16907-6).

7 Design of earthworks for cuttings

7.1 General

Excavation should be undertaken in a systematic and planned manner to maintain quality of the excavated soil used in embankments. Rain and subsurface water shall be collected by a system of graded slopes, open ditches and drains. Over-excavation or formation of temporary steep unstable slopes shall be avoided. Process of excavation shall be documented in the site records. (see prEN 16907-3).

7.2 Materials involved

Apart from geological classifications, materials involved in the excavation of cuttings can be classified according to the construction procedures that are needed, in order to be built.

A first approach to this topic should be (see prEN 16907-3):

- strong to intermediate rocks (blasting);
- intermediate to weak rocks (ripping);
- soil (diggers are enough for excavation).

The potential excavability of cuttings can be preliminarily estimated by means of geotechnical and geophysical investigation and *in situ* testing.

Also this part of investigation shall be focused on the knowledge of the relevant properties of the materials inside the cutting, from the point of view of their ability in order to be used for building embankments.

As the foundation of infrastructure itself, the characterization of the subgrade (bottom of the cutting) needs special care.

7.3 Geometry

The design of slopes in cuttings for infrastructure shall provide their stability in both short and long-terms. This aspect has much to do with the relevant properties, geological nature and structure of the materials inside them.

The design of slopes on cuttings shall take account, at least, of the following:

- type of infrastructure and security level required (see 7.5). Availability and type of maintenance;
- height of the cutting;
- right-of way;
- materials involved (see 7.1);
- geological structure: overall framework of the cutting, and detailed behaviour of each formation;
- drainage conditions (see 7.4);
- existence of uphill buildings or infrastructure.

Every single formation involved has its own specific stability patterns, highly affected by drainage conditions. Thus the slopes in a cutting can be either constant of variable (in both sides and at different heights).

The design can also include one or various berms located at intermediate heights all over the cutting or in specific places. They should be designed in order to be stable and to allow inspections and maintenance works on the slope: thus minimum dimensions for machinery, knowledge of the materials involved, and drainage conditions shall be defined.

7.4 Drainage

Drainage conditions are very relevant in order to provide both, stability to the slopes, and an adequate performance of the bottom (subgrade), from the point of view of the serviceability of the infrastructure.

Clause 10 of this document details the principles of drainage.

7.5 Overall stability

Cuttings shall be designed to be stable earth-structures. Overall and slope stability shall be assessed in accordance with EN 1997-1. Also considerations about geometry included in 7.3 shall be taken account.

NOTE Weathering formations can largely vary their long-term behaviour in terms of excavability, slope stability and other relevant properties.

7.6 Relevant properties of the cutting base (subgrade)

The base of the cutting is the platform in which infrastructure will be placed. The required properties of the earthwork material that form the base of the cutting will normally be specified by the client or determined by the geotechnical, structural or pavement engineering design. The geotechnical investigation shall clarify the anticipated ground conditions (see 5.2). The earthworks design shall include an assessment of whether these required properties can be satisfied, and if appropriate identify additional earthworks measures necessary to improve the ground (e.g. excavation and replacement of soft soils).

The earthworks construction activities shall be planned by the earthworks construction Contractor to avoid an unacceptable degree of deterioration of the ground conditions as a result of the earthworks activities. In cuttings within soil this will normally require particular attention to be given to the appropriate form of earthworks drainage installed either as or immediately after a cutting is extended to a particular level.

The earthworks designer shall identify ground conditions that present a clear risk to the construction within cuttings (e.g. high porewater pressures within silts and fine sands) and specific requirements to be included as a minimum requirement during construction (e.g. the requirement for drainage to be installed in advance of certain elements of the earthworks). See 4.6 for further details.

It should be noted that transitions from cuttings to embankments require special consideration in terms of the above issues because drainage conditions at cuttings can be particularly difficult (see Clause 10).

8 Design of earthworks formed by dredging and hydraulic placement of fills

The design and execution of dredging works to construct hydraulic fills are both considered in prEN 16907-6, but their design has many common features with that of embankments and excavations made "in the dry".

Materials are taken from a "source" zone (borrow area), transported to their final location and then hydraulically placed to create a land reclamation. These operations are detailed in prEN 16907-6.

The required properties of the completed embankment can either be obtained without specific action, when the dredged materials have favourable geotechnical properties and specifications are met, or need improvement in terms of stiffness, stability, density (e.g. to prevent liquefaction) or resistance, when the dredged materials have poor characteristics and specifications are stringent.

The selection of the fill material is not always "free", depending on the main aim of dredging, which can be to excavate the bottom of seas or rivers to a given profile, whatever the nature of the ground to be extracted, or, adversely, to construct land reclamations using selected materials available in dedicated borrow areas.

The zone to be dredged needs careful site investigations to assess the nature and state of existing soils and the possibility to dredge and use them as a fill material. The stability of the slopes limiting the (borrow) dredged area should be assessed, together with the possible spill of fine particles during dredging and the presence of polluted materials.

For the hydraulically placed fill, the designer should consider both the settlement of the foundation ground due to the fill load and the self-weight settlement of the fill. The movements within the fill may be limited by controlling the placement of the dredged materials. The required surface stiffness and resistance may be obtained by compacting the surface layers above the water level, and using ground improvement techniques for the underwater part of the land reclamation.

9 Design of earthworks for hydraulic placement of mineral wastes

PrEN 16907-7 relates to the hydraulic placement of soils and mineral wastes derived principally from terrestrial mineral activities, i.e. from land-based mineral extraction operations and is, in part, driven by recent changes in EU Regulations governing the engineering of the associated confining facilities. However, prEN 16907-7 can implicitly be considered in a wider context as the technical basis could equally apply to fly ash, sewage sludge and a range of other hydraulically placed industrial by-products.

Hydraulic placement is used extensively for the efficient disposal of both organic and inorganic soils in a broad range of industrial situations and prEN 16907-7 therefore covers the widest range of engineering applications. The principal elements are not only the use of hydraulic fills for the placement, stabilization, reclamation and rehabilitation of processed soils and mineral wastes in a terrestrial environment but also, and of great importance in a regulatory and environmental context, the need for both:

- safe and stable confinement during placement;
- surface stabilization on cessation of operations to aid rehabilitation.

Though the primary driver for the prEN 16907-7 will be mineral/extractive operations, due to their ubiquitous and enduring nature, other industries fall within its scope. It therefore addresses all geotechnical aspects of the investigation, design, implementation, monitoring and rehabilitation of processed soils and mineral wastes deposited using hydraulic filling techniques and, in summary, covers the following stages of the process with respect to their influence on the geotechnical properties of the final structure:

- excavation - the extent to which geology, mineralogy and the extraction process influence both geotechnical and geochemical characteristics of the particulate waste;
- process - the extent to which comminution and processing (both physical and chemical) modify and influence the characteristics of the hydraulic fill;
- transport - the influence of material characteristics on selection of the transportation options for the hydraulic fill;
- placement - the influence of geotechnical and geochemical characteristics on placement methods for the hydraulic fill in order to achieve storage efficiency and to optimize rehabilitation;
- structure - the structural engineering options available for the confinement, storage and closure in order to achieve a safe, stable and environmentally acceptable end point for the depository.

The principal objective is therefore to deposit the soils and mineral wastes by hydraulic placement in a custom-built and properly designed storage facility. The depository for such materials may vary in area from less than 1000 m^2 to several square kilometres, and in height from a few metres for an aggregate silt lagoon to several hundreds of metres for a tailings management facility for a large and complex polymetallic mining operation. PrEN 16907-7 provides designer, operator and regulator with the framework for the design and construction of the storage facility to meet requisite regulatory standards and to comply with good practice.

10 Drainage

10.1 Drainage for collecting water

Drainage is a major component of earthworks, both for excavations and embankments. It influences the stability of slopes, and the performance of: embankment fill materials, the base of cuttings, and any overlying infrastructure. Two main types of drainage systems can be considered:

— superficial drainage concerns runoffs from rainfall, snowmelt and other meteorological phenomena;

— underground drainage is aimed at collecting groundwater from any origin (infiltration, water tables, etc.).

The earthworks designer should identify the likely pathways for significant water inflow that are likely to have an adverse effect on the earthwork (Figure 8), either during or after construction; and identify appropriate temporary and permanent drainage measures. Each case requires a specific design which is likely to be developed by the project drainage engineer who will consider issues such as flow capacity, outfalls, and maintenance requirements. Figure 9 presents an example of drainage system for a half cut/half fill profile. Figure 10 shows an example of drainage system for an embankment built on a slope. The earthworks engineer should also consider potential consequences of failure of the drainage system on the completed earth-structure.

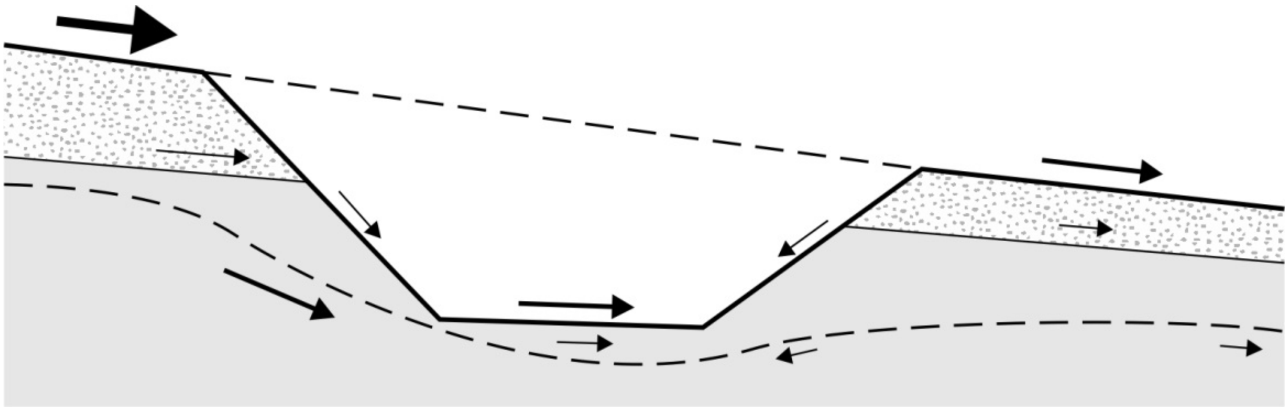
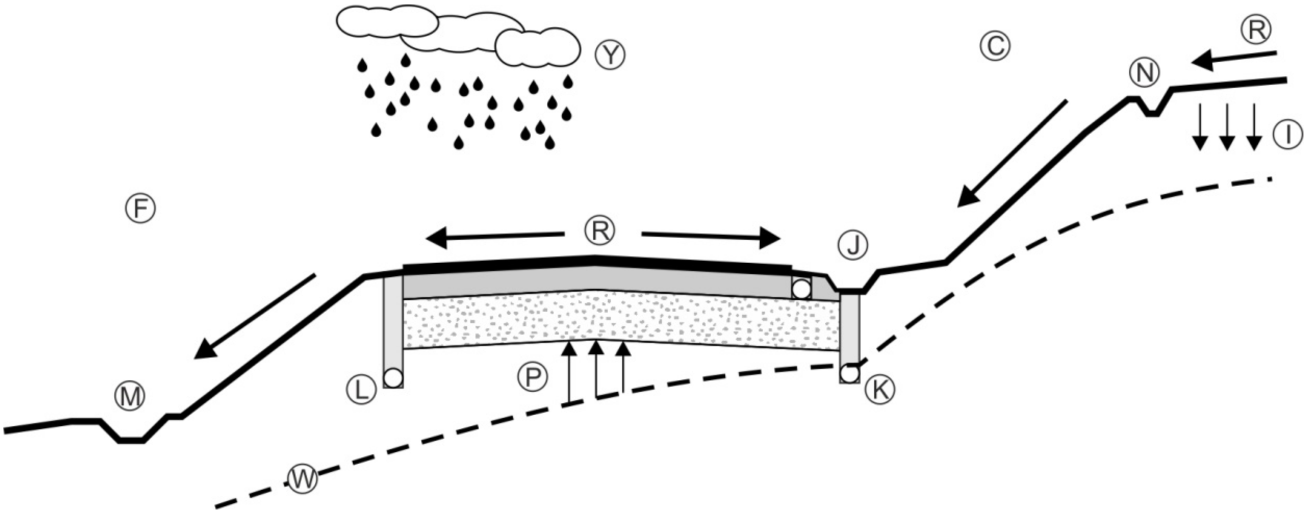


Figure 8 — Identification of water flowpaths at a cutting for earthworks drainage design



Key

C – cut

M – embankment ditch

F – fill

N – crest ditch

I – infiltration

P – capillarity

J – superficial drainage

R – run off

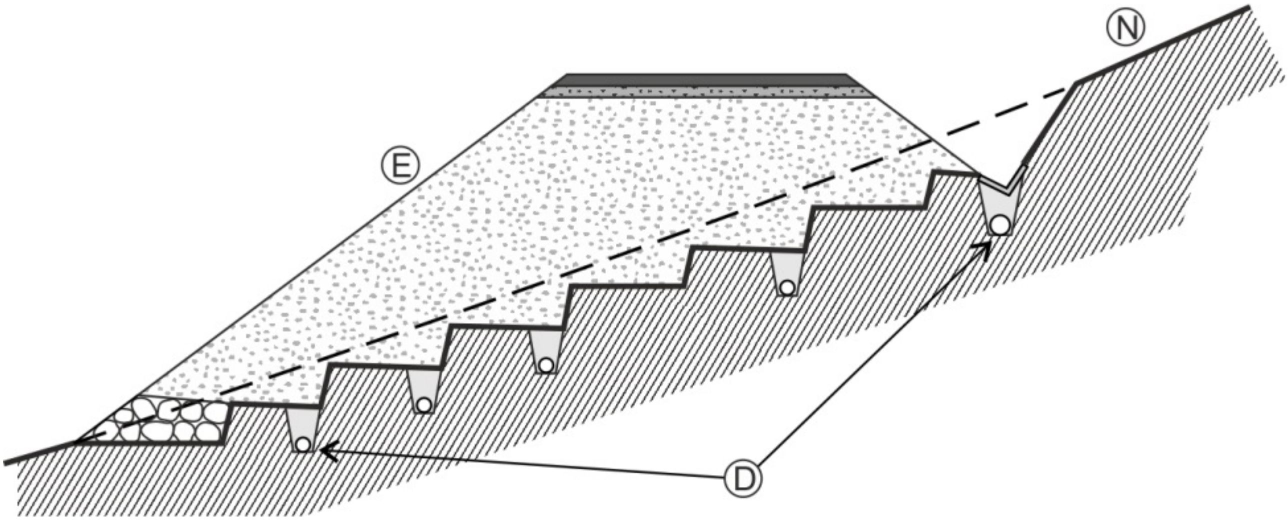
K – underground drainage

Y – rainfall

L – superficial and underground drainage

W – water table

Figure 9 — Example of superficial and underground drainages for a half cut/half fill profile



Key

E – embankment

D – longitudinal drains

N – natural ground surface

Figure 10 — Example of longitudinal drainage along a road or railway embankment built on a slope

If the water content of the fill material within an embankment increases significantly above the as-placed water content then there is a potential for a reduction in strength or volume of the placed fill material. Thus the earth-structure itself or the superstructure (e.g. railway track, road or buildings founded on the embankment) can be damaged. The penetration of water into an embankment, or rise of water into the base of cuttings, should therefore be either prevented/minimised, or allowed for within the design (selection of fill materials and compaction regime, soil stabilization).

When the ground water table is high, the water can seep from the natural ground into the foundation layers of a cutting. The earthworks design should either allow for this condition or include a requirement for the foundation layer to consist of permeable material permitting the pore water to run into the side drains without pressure. Drains can be made of geotextiles or of mineral aggregates. Fill materials used for drains, or fill layers that have a drainage function, shall not be swelling, collapsible or soluble when reacting to water.

The seepage of water from an earthwork cannot always be avoided. If seepage water can stream out on the earthwork slope then where possible it should be intercepted by drainage in order to avoid soil erosion. The design of the drainage should consider appropriate filter rules in order to avoid contact erosion. In situations where water may flow through an earth-structure the design shall consider the need to prevent the onset of piping.

10.2 Protection of slopes against erosion

Erosion on shoulders of embankments and on slopes in cuts, due to their direct contact with air and water (liquid and in form of ice and snow), have to be controlled.

Special problems of erosion on embankment shoulders are due to the behaviour of compacted materials in relation with wind, water runoff, and freeze and snow actions.

Thus when erosion can be considered a problem, the action should be directed to isolate or diminish the interaction among them. Some typical actions are:

— providing a manmade barrier (impervious or not, commonly a geocomposite, organic blanket, etc.), over the shoulder of the slope;

— providing an adequate vegetal barrier;

— when excessive erosion (or even dissolution) can take place due to the use of soluble materials on the embankment, a different and impervious (clayey) slope shall be built;

— when excessive circulation of water on shoulders is due to the direct spill from paved embankments, then an adequate dispositive (kerb on the top, or drainage over the shoulder…) shall be designed;

— other specific designs.

11 Optimization of earthworks project design

Once all necessary information about available materials, their possible use and corresponding processes has been prepared, a global assessment and optimization of the earthworks project shall be made. Optimization concerns both the earth movement between excavations, external resources and embankments and the use of equipment to perform the works. Since earthworks construction is significantly affected by weather conditions, the design can seek to minimize the impact of short-term adverse weather, but the construction may have to be suspended during months of poor weather. Consideration should be given to the likely impact of weather conditions at a site when planning the optimal project.

The optimization of earth movement shall aim at:

— reducing the transport distances between extraction and filling sites at the scale of the whole project (while accounting for existing obstacles such as railways, rivers, etc.);

— re-using the largest possible part of the site materials in the structures to be built, considering the possible ways of using materials, eventually by treating them. This may interfere with the geotechnical specifications for the excavation/cut and embankment structures;

— achieving maximum efficiency of the equipment used at the different stages of works, while meeting the planning requirements for the project.

Optimization shall account for the impact of climatic conditions and hazards, and their seasonal variations on the various earth movement scenarios.

Optimization by design will limit the impacts of earthworks on the environment through:

— reduced need of natural resources from outside the construction site;

— reduced need of sites to dispose the materials which are not used for fills;

— reduced need for land;

— reduced energy consumption and production of greenhouse gases;

— reduced nuisances (noise, vibrations, damages to local infrastructures).

Optimization requires:

— the precise characterization of site materials and classification of resources with respect to the global needs of the project;

— the analysis of possible technical and economical solutions and of their impact on the structures to be built on top of them (capping layer and pavement, rail track, foundations for building,…), in terms of mechanical performance, maintenance cost and durability;

— the application of quality insurance procedures, covering studies, construction and control.

12 Specifications for earthworks

12.1 General

The construction works are controlled by an earthworks Specification, which is a document prepared for the project, it details the requirements for earthworks on the project. This document should be prepared once the earthworks design has been undertaken and the required fill material properties have been established. A Specification should adequately describe the design requirements that are to be satisfied, be easily understood by the parties to the contract, be practicable and capable of both enforcement and measurement, and not be unnecessarily costly or time consuming in its application. It should be capable of being monitored by an effective form of quality assurance procedure (prEN 16907-5).

The design requirements for the earth-structure are set out for the earthworks Contractor via a Specification and a set of construction drawings. There are three main types of specifications for earthworks:

— end product;

— method;

— performance.

It may be appropriate for a project earthworks Specification to incorporate different forms of earthworks Specification for different types of fill material, e.g. method compaction for general fills and end product compaction for coarse granular fills. Besides, some aspects of the control may include different types of specification (e.g. surface topographical control of layers in a method Specification or maximum thickness of layers in an end product Specification).

The specification shall include any conditions to be satisfied during construction to ensure that the following general requirements are satisfied:

- materials used should be chemically suitable for the environment in which they are used; some material might require treatment (e.g. stabilization or remediation) and consent prior to use;
- materials used should be durable (not prone to deterioration) and non-biodegradable;
- the earthworks should provide a stable finished surface that will not suffer unacceptable post construction settlement or movement within the fill material;
- the earthworks should provide a surface of sufficient stiffness (and or shear strength) for the intended end use (if a stiffness value to be achieved is specified then the value will need to consider both the imposed load and settlement induced by the loaded area);
- the works can be constructed, maintained and demolished safely.

The specification should provide as a minimum the following information:

a) types of materials permitted for use in the earthworks together with material properties;

b) performance requirements to be met (for end product and performance Specifications);

c) requirements for the disposal of unsuitable material;

d) requirements for placement, spreading and compaction of the earthworks materials;

e) requirements for the treatment of exposed surfaces;

f) requirements for the testing and verification of compliance.

On many projects, the earthworks Specification will be based on a standard document that has been developed based on extensive experience. In most European countries, these documents have been developed by road, railway, waterway or airport authorities to suit the particular engineering requirements of that industry and the geological and climatic setting of the country. The level of detail of these documents varies, and in many cases, there is a requirement for the Designer to set out the specific requirements for a particular project. Where the client sets the requirement for the form of Specification to be utilized then the Designers role will be to determine the project specific requirements.

On projects where there is no existing standard Specification to be implemented, the Designer has the option to either prepare a standalone document or adopt an existing standard form of Specification. When an existing standard document is to be adopted, then it should be a well-established method that is appropriate for the nature of the works/climate/fill type and is based on extensive laboratory and field trials; examples of good practice are included in informative Annexes C to H.

When selecting or preparing the Specification for the project, the Designer shall consider various issues, including the following:

— identify whether an existing specification is appropriate for the type of earthworks project, e.g. will the loading criteria of the project exceed that allowed for within the existing standard document;

— special cases such as hydraulic fills require a specification developed specifically for the type of work.

— engineered fills which are used to produce suitably shaped landforms for structures should be constructed to high standards to minimize the risk of ground movements causing damage to property built on shallow foundations. Specifications based on those developed for highway embankments are not necessarily appropriate for fills on which buildings will be founded since acceptable settlement is likely to be significantly smaller for a building than for a road; hence a more stringent specification might be necessary than for highway purposes;

— highway schemes are often major civil engineering projects, whereas schemes involving low-rise buildings founded upon engineered fill are often relatively small in scale. Control procedures should be appropriate to the scale of project and criticality of settlement tolerance. Control procedures for large highway projects may not always be the most suitable for fill being placed as, for example, part of a small housing development.

12.2 End product Specification

In this case, the Specification defines the degree of compaction necessary for the given material by reference to criteria linked to either serviceability or ultimate limit states. The level of compaction required is normally expressed in terms of selected geotechnical properties e.g. percentage of maximum dry density or prescribed minimum stiffness and is supported by on-site earthworks testing.

Where an end product Specification is used, the requirements normally define overall targets to be achieved without detailing the methods to be used to achieve the targets. The Specification should describe the requirements that have to be satisfied by the earth-structure as a whole and may also include different partial targets that have to be verified (e.g. minimum requirements for a layer before spreading the next one).

An end product Specification may be used to control earthworks provided that the approach will adequately control the various issues that affect earthworks.

The above criteria are associated with showing that the works should be constructed so that they are suitable for the proposed end use. To achieve these objectives the earthworks Contractor and the designer should consider a range of practical issues, and to deliver this should effectively require that a method of working/specification is put in place (whoever writes this document will effectively become an earthworks Designer, see 6.3). In most cases, it will be necessary to implement an earthworks Quality Control system during the earthworks construction (even though this is not required by the Specification) to ensure that the material placed is likely to achieve the end product requirement, and will be stable in the long-term (e.g. post compaction changes in moisture content will not result in an unacceptable deterioration of the fill material).

12.3 Method Specification

Method Specification defines how compaction should be conducted in terms of the types of compaction plant, method of operation, number of passes of the plant and the final thickness of the compacted layer. These specifications have been developed from research using full scale testing of plant and should be used either in full or not at all. If the Designer chooses to use an existing established method Specification, then the project shall also implement the classification system that it is based on (see Clause 9, and prEN 16907-5 for classification and prEN 16907-3 for compaction methods).

When a method Specification is to be utilized on a project, then it should be a well-established method that is appropriate for the nature of the works/climate/fill type and is based on extensive laboratory and field trials; examples of good practice are included at informative Annexes C to H. The Specification should include a limited number of *in situ* density tests to confirm that the degree of compaction achieved by the method is as expected.

If a well proven experience based method Specification does not exist, then an appropriate method of compaction can be assessed by well controlled site trials for the fill material and plant that is proposed. This approach will enable the Contractor to manage the site works efficiently. However, in this situation it is likely that the works would still be approved by an end product Specification.

12.4 Performance Specification

Performance Specifications require the works to be defined relative to long-term project requirements, which are commonly set at a relatively high level. For example, the criteria may be defined based on the long-term fitness for use of a building that is to be formed upon the completed earthwork. A limitation of this approach is that any failure to meet the criteria will only become apparent after construction, which will often be too late for corrective action to be implemented. Performance Specifications are commonly used for embankments formed of dredged fill (see prEN 16907-6) because there is little opportunity to test the fill material during placement. However, for embankments constructed in dry conditions it is generally preferable to manage the works by end product or method specification that set clear controls on the construction of the earthwork.

If a performance Specification is to be provided, then it should be defined in terms of the required serviceability limit state. For example, the maximum permissible ground movement during a specified period may be stated as a differential settlement in terms of a tolerable gradient over a defined length, subject to a maximum permissible settlement at any point. However, while the performance Specification may only consider the completed surface of the earthwork, the Designer may need to consider the behaviour of both the embankment (which is covered by this standard) and the underlying ground (which is not covered by this standard).

This may be considered an onerous form of specification from a contractual viewpoint as it seeks to place the risk for all future events on the Contractor and might be very difficult to monitor in practice. Therefore, when this form of specification is implemented the earthworks team should undertake appropriate form of Quality Control even if this is not required by the Contract as per 12.2 above.

It should be noted that this topic is not included within prEN 16907-5 because it is not compaction control related testing.

12.5 Additional requirements for deep fill areas/buildings and structures

Collapse compression upon groundwater inundation is a major hazard for buildings and other structures on significant thicknesses of fill; therefore the Specification of placement and compaction of the fill should be designed to eliminate collapse potential.

NOTE The risk of collapse upon inundation is particularly high where fill is placed below the potential groundwater level (e.g. infilling of a quarry), but is present at many other sites due to risk of inundation following a water main burst.

It should be noted that, the collapse potential of some fills will not be eliminated despite the achievement of a field dry density equivalent to at least 95 % of the maximum dry density achieved using the standard proctor test. Consequently, in such cases, dry density should not be relied upon to provide an adequate measurement for compaction specification. Where there is an unacceptable risk of collapse upon inundation the Specification should include a requirement for all fill to be compacted to < 5 % air voids. Soil stabilization using binders is a possible option.

13 Execution of earthworks

Earthworks are divided into a few basic tasks, which are combined in a specific way for each individual project. The succession of these tasks is specified by the “earth movement”, which predetermines the future of each cubic meter of extracted soils or rocks (or secondary or reused materials). The execution of each task is linked to the material, the equipment, the available time and the climate. The material properties condition the equipment to be used and the whole construction process.

A typical succession of tasks for an infrastructure project consists of the following actions: implantation of the project on site, preparation of the construction site, excavation works on site or outside, transportation of materials to be used as fill, eventual replacement of part of the natural ground under embankments to be built, execution of the embankments (preparation and treatment of fill materials, compaction), drainage works, construction of secondary structures.

Different specialized technologies and processes may be used for each elementary task. The choice among these many possibilities is part of the design of earthworks (Clause 5).

Other parts of the prEN 16907-series cover topics related to the execution of earthworks, and these parts can be summarized as follows:

— execution of earthworks is the scope of prEN 16907-3.

— treatment of materials with binders is the scope of prEN 16907-4.

— quality control is the scope of prEN 16907-5.

— land reclamation with dredged hydraulic fill is the scope of prEN 16907-6.

— prEN 16907-7 concerns the hydraulic placement of soils and mineral waste.

14 Monitoring earthworks and checking earth-structures performance

14.1 Introduction

Monitoring and checking shall be performed from the beginning of earthworks on the project site. They aim at:

— controlling the progress of works;

— validating the geotechnical assumptions made during the design of the earth-structures and of the corresponding earthworks;

— gathering necessary elements to the acceptation of the completed structure by the client.

The extent of monitoring and checking activities should be adapted to the size of the project and the level of risk. Many of these items are resolved by the establishment of a QA/QC system, which should be an important element of the earthworks design, see prEN 16907-5 for details.

14.2 Needs and techniques for monitoring and checking earthworks

Monitoring can be applied to various aspects of the earthworks:

— the nature of ground (description);

— the mechanical behaviour of the ground and fill materials (for geotechnical justification, following EN 1997-1);

— the water content and climate;

— the efficiency of the excavation, treatment and compaction processes (equipment and methods).

Checking shall be performed at all design stages of construction. It applies to:

— the final state of compacted fills (dry density and water content);

— the geotechnical behaviour of the completed structures (deformability, permeability, resistance);

— the final geometry of the structure;

— the efficiency of drainage.

This can be coordinated with the observations made on the deformations and stability of the structure, during the construction works and the exploitation period (Long-term monitoring).

Techniques

The techniques used for monitoring and checking include:

— observations and tests for ground description;

— rainfall and climate observation and tests for water content;

— compaction control (thickness of layers, density measurement by various methods);

— observation of anomalies (slides, mattressing, collapse of fill material, settlement, unforeseen type of soil or rock);

— measurement of moduli and resistances by means of plate load tests, pressuremeter tests, penetration tests;

— permeability tests;

— geometric measurements (topographic methods, settlement and horizontal movement measurement techniques);

— pore pressure measurement;

— special techniques (e.g. measuring of strain in geosynthetic reinforcement).

Criteria

Monitoring of earthworks is used to:

— detect as soon of possible any significant departure from the project;

— validate the successful achievement of each stage of the construction works.

The criteria depend on the type of earth-structure (excavations and slopes, embankments, hydraulic fill from dredging, etc.) and on their future use (construction of buildings, roads, railways, canals, landscaping fill, etc.). The criteria should be defined during the design of the civil engineering (earth-structure) project and be part of the requirements put on the execution of earthworks, thus on the earthworks project.

Consideration should be given to the benefits to be gained of preparing a report towards the end of the construction phase, sometimes referred to as a “Geotechnical Feedback Report”, this can be used to summarize important information relating to the earthworks construction and the findings of the monitoring. This document can be extremely advantageous to the asset management (operation and maintenance) of the earth-structure.

14.3 Checking earth-structure performance

Checking is performed to assess the conformity of the built structure to the specifications:

— density requirements;

— required mechanical behaviour;

— geometry;

— durability (protection against water, frost).

The criteria depend on the type of earth-structure (excavations and slopes, embankments, hydraulic fill from dredging, etc.) and on their future use (construction of buildings, roads, railways, canals, landscaping fill, etc.). The criteria should be defined during the design of the civil engineering (earth-structure) project and be part of the requirements put on the execution of earthworks, thus on the earthworks project.

15 Use of national experience and non-conflicting rules

15.1 General

Earthworks rules and suggested procedures, which are the heart of the different parts of this standard, are either principles, which apply to any situation, or experience-based rules, which usually differ for different materials and climates and can result from local or national practice, including specific ways of collecting experience and expressing the corresponding rules. The collection and preservation of national experiences is one of the fundamentals of this document. Informative annexes devoted to national practices aim at sharing information on existing systems and offering the possibility to the standard users to benefit from these experiences.

The existence of national standards complementing the present one, by non-conflicting rules, is allowed.

15.2 Informative examples of experience-based national practices

Existing practices cover the whole process of design, execution and control of earthworks, to transform materials from different sources into earth-structures with specified properties. This process consists of three successive, though interrelated stages:

— Stage 1: Based on the available information, selection of the materials which can be used to meet the needs (in terms of volumes and required properties) of the earth-structure:

  — classification (assignment) of materials into groups based on intrinsic properties;

  — definition of possible uses without and with treatment (experience based classification or new tests);

  — choices and preliminary optimization (volumes and destination).

— Stage 2: Organization (design) of earthworks (including extraction, transport, eventual treatment, compaction):

  — further specific classification including state and other parameters;

  — definition of the compaction process as a function of initial state, climate, treatment, preferred or available equipment, etc.;

  — final optimization (equipment, schedule), which produces the “earth movement” and optimal use of equipment.

— Stage 3: Organization of the control of earthworks:

  — selection of tools (method and equipment);

  — definition of acceptance criteria for the completed earth-structure.

The detailed implementation of these staged practices, which cover the contents of prEN 16907-2, -3, -4 -5 and -6, has been described in different ways. Informative Annexes C to H explain how these practices have been organized in different European countries.

Annex A
(informative)

Example of procedure for the validation of the compaction process for a given fill material. Organization and execution of trial sections

Full-scale compaction tests may be used for the selection of a suitable compaction process for a given material (preliminary tests) or to check that the selected compaction process for a given material gives the expected result (acceptance test).

In order to achieve reliable deductions from the tests, the experiments shall be carefully organized. The objectives of the tests shall be clearly formulated, together with the quantitative data that will be used for the evaluation of the results.

The following issues shall be specified:

— the factors that will be tested and those which will be kept constant (type of soil, layer thickness, type of compactor, compaction energy, number of passes, etc.);

— the successive values given to each tested factor;

— the measurement methods used and the number of measurements;

— the method used to analyse the results and prepare conclusions.

This will result in a test programme. The test programme specifies the number and location of the test fills, the fill material used, the way it will be brought and laid in layers, the compaction procedure and the measurements. The needed staff and competencies will be identified. The compacting equipment will be checked and the eventual anomalies noted.

Tests results are collected and analysed in terms of mean value and standard deviation. The results are presented in a report, where results have to be traceable.

Usual dimensions for a trial embankment are a length of 30 m and a width equal to three times the width of the compactor, the measurements being made on the central lane.

The evolution of the density varies linearly with the logarithm of the number n of one-way passes. Thus the successive numbers of passes should be in geometric progression (2-4-8-16…).

The optimum water content and density shall be determined on the actual tested material.

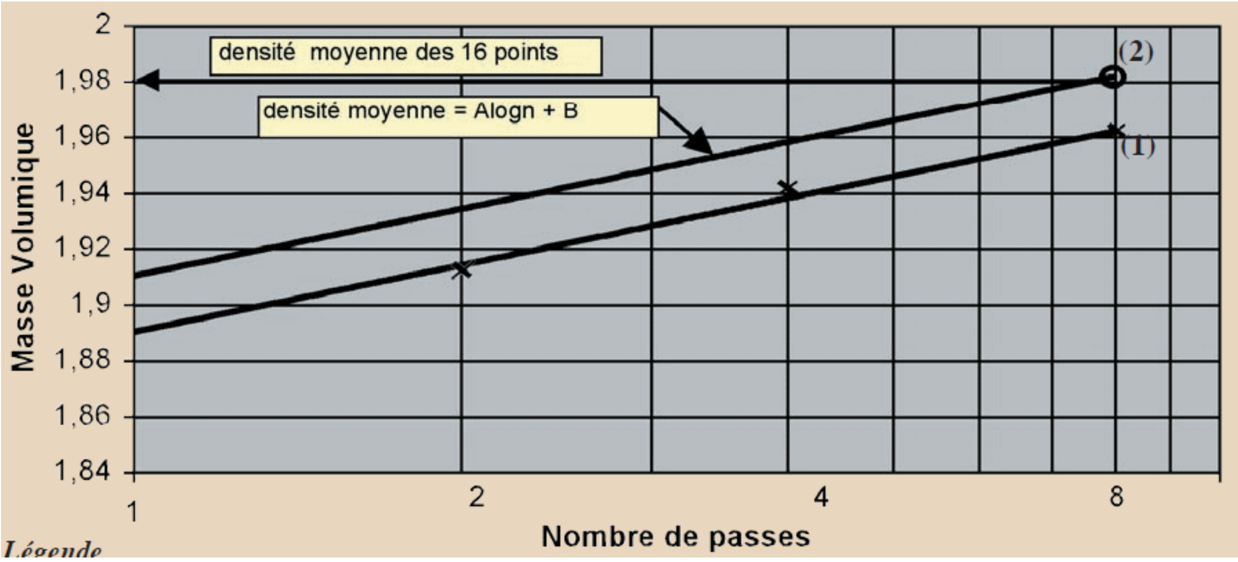
Measurement of the average density of the compacted layer $\rangle_{dm}$.

The minimum number of measurement points is 6. The measurements are made at the same locations for the various levels of compaction (Figure A.1).

At the final level of compaction, the total number of points can be increased (for example 16 points) in order to better assess the obtained density. The $\rangle_{dm} = f(n)$ curve can then be corrected.

When the compaction process aims at obtaining high resistance and stiffness, the density at the layer base ($\rangle_{db}$) and the density gradient [curve $\rangle_{d} = f(\text{depth})$] can be measured, in particular treated fine soils. The density gradient is useful to evaluate the eventual compaction difficulties. The densities at the layer base can only be measured at the end of compaction. They should be measured at 4 points at least, but preferably 6 points. They are usually assumed to evolve as the mean densities $\rangle_{dm}$ when n increases.

In the case of coarse materials, the density of which cannot always be precisely measured, the measured settlement of the layer surface at 20 points can be used to assess the evolution of the mean density with n. Penetration testing can be used to assess the decrease of their densities with depth.



Key

×: mean values of the six values of average density after 2, 4 and 8 passes

O: mean value of the 16 values of average density after 8 passes

(1) variation line for the six “x” points (regression)

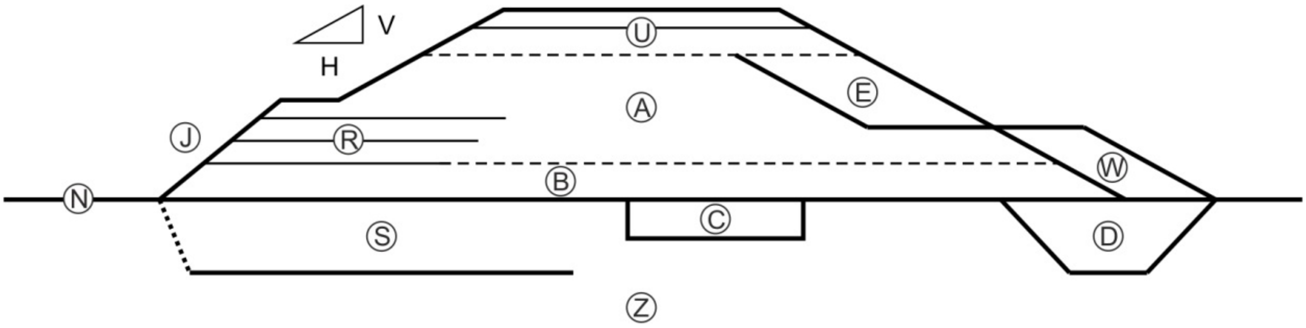
(2) variation line translated from the preceding one, to account for the 16 points

Figure A.1 — Analysis of measured densities on a trial fill

Annex B
(informative)

Geometry definitions for earthworks and earth-structures

This informative annex presents some drawings used to define the meaning of words used for embankments.

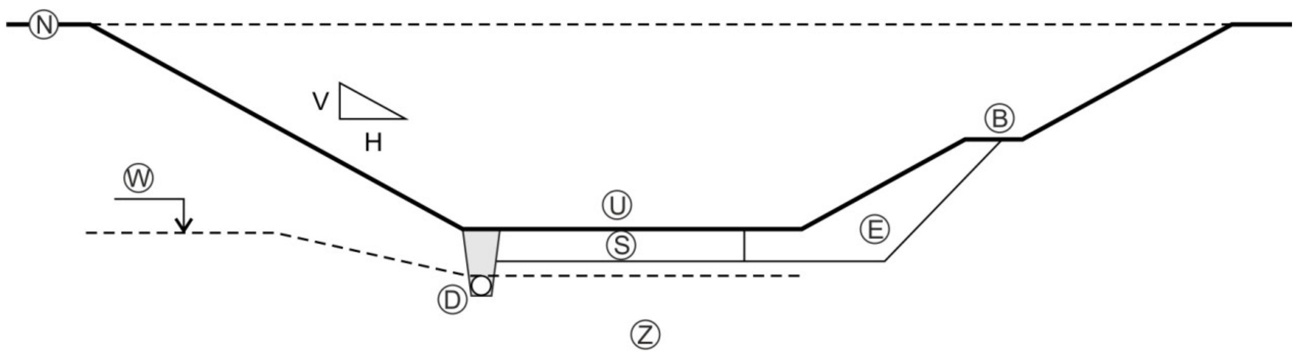


Key

A –	current fill	R –	reinforced fill
B –	embankment base	S –	(substitution)
C –	(purge)	U –	capping layer / upper part of fill
D –	(bêche)	W –	berm
E –	(encagement)	Z –	supporting ground
J –	steepened slope	H –	horizontal
N –	natural ground surface	V –	vertical

Note: These names come from French.

Figure B.1 — Words used to describe embankments



Key

B – berm

D – draining trench

E – (masque)

N – natural ground surface

S – (substitution or purge)

U – upper part of fill

W – ground water level

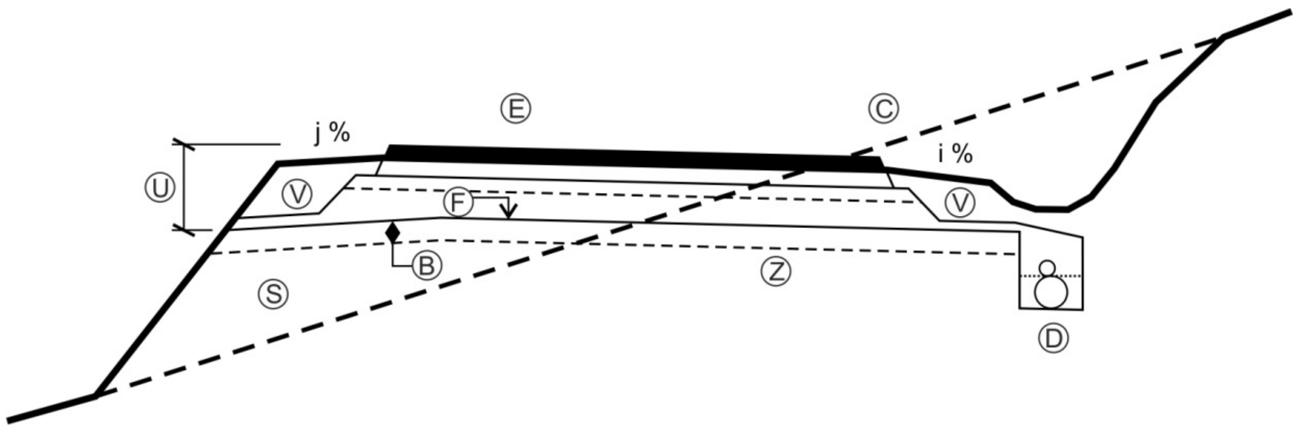
Z – subsoil

H – horizontal

V – vertical

Note: These names come from French.

Figure B.2 — Words used to describe cuttings



Key

B – substructure, subbase

C – cut / side cut

D – road side drainage facilities

E – embankment

F – formation level

S – substructure

U – superstructure

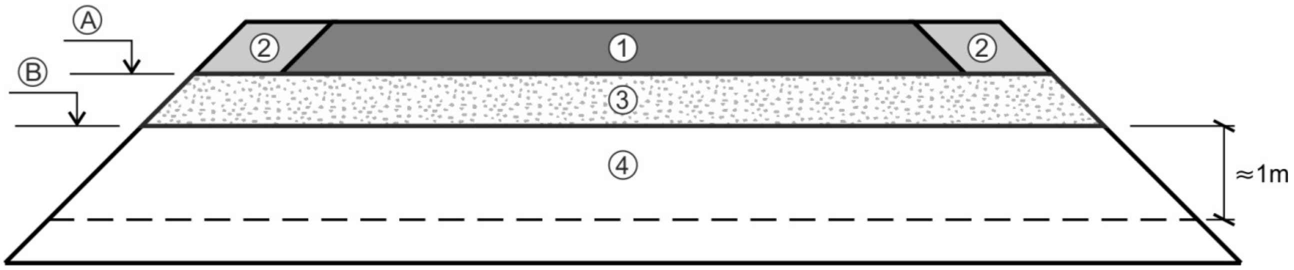
V – verge

Z – subsoil

i – angle (slope)

j – angle (slope)

Figure B.3 — Words used to describe half fill/half cut road embankments



Key

A – road support platform
B – fill surface
1 – pavement layers
2 – shoulders
3 – capping layer
4 – upper part of fill (embankment) or natural ground (cutting)

Figure B.4 — Words used to describe road embankments

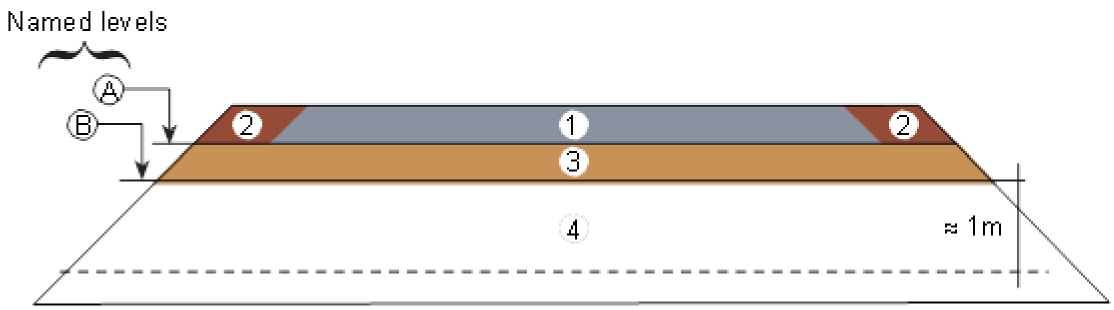
Annex C
(informative)

Summary of national practice - France

C.1 Introduction

Earthworks rules applied in France are based on test and classification standards and guides prepared mainly by public organisations. These documents follow the same stages as indicated in the present standard: global geotechnical study, material classification, execution of works design using classification and other parameters and associated execution procedures. The core system was established for road construction; similar rules exist for railways, dams and the building sector.

Specific terms for road construction are shown in Figure C.1.



Key

A. road support platform (PF)

B. fill surface (AR)

1. pavement layers
2. shoulders
3. capping layer
4. upper part of fill (embankment) or natural ground (cutting) (PST)

Figure C.1 — Definitions for road structure

C.2 Classification of materials

Site investigations are when possible organized in successive stages, covering site inspection, use of topographic and geological maps, aerial photos, drilling and excavation for soil and rock sampling, groundwater measurements, field and laboratory tests and geophysical investigations. These investigations aim at defining a geological model, identifying and studying geotechnical issues (compressible zones, karstic zones, unstable slopes, etc.), defining the conditions for extracting materials, their potential use and conditions of use, and making an estimation of the mass earthworks balance.

Some 40 years ago, much effort was put in expressing the national experience of earthworks in the form of a classification system, where materials are gathered in groups with similar behaviour during the execution of embankments and capping layers. This system, which is similar to the classification system presented in prEN 16907-2, is described in the “Guide for the execution of embankments and capping layers" (SETRA/LCPC, 1992) and in French standard NF P11-300. It is based on the intrinsic properties of the materials.

Three main groups were established:

— soils;

— rocks;

— organic soils and industrial by- or co-products.

A. Soils group

Soils are natural materials, made up of grains which can easily be separated simply by crushing or by the action of a stream of water. Those containing a percentage of organic matter larger than 3 % are defined as organic soils.

The soils group is divided into 4 main classes:

— class A - Fine soil;

— class B - Sandy and gravelly soil with fines;

— class C - Soil containing fines and large elements;

— class D - Soil insensitive to water.

These classes are sub-divided into sub-classes: A1 to A4, B1 to B6, C1 to C2 and D1 to D3, on the basis of particle size distribution and interaction of fine soils with water:

— three particle size characteristics are used: the size D_{max} of the largest element contained in the ground, the fines percentage ($C_{80\mu m}$) and the percentage of particles with a size less than 2 mm (C_{2mm});

— the plasticity index (I_P) and the methylene blue value (V_{BS}). Both values can be measured on every soils, but V_{BS} is preferred for soils with limited clay activity ($V_{BS} < 2,5$) and I_P for soils with a moderate to high clay activity ($I_P > 12$).

For further classification, other parameters such as hydric state, friability of particles and their behaviour under attrition are measured. These are used to select the most appropriate earthworks processes (C.3).

B. Rocky materials group

The classification of rocky materials is primarily based on geology.

Sedimentary rocks are divided into 5 classes:

— R_1 class is the class of Chalks. These are classified according to their dry density ρ_d and their moisture content w_n. Based on these parameters, the class is divided into three sub-classes (R_{11}, R_{12} and R_{13});

— R_2 class concerns the sundry calcareous rocks. The more compact calcareous rocks are classified according to their behaviour under attrition (micro-Deval test), while softer rocks are classified according to their bulk unit weight. The sub-classes go from R_{21} to R_{23}.

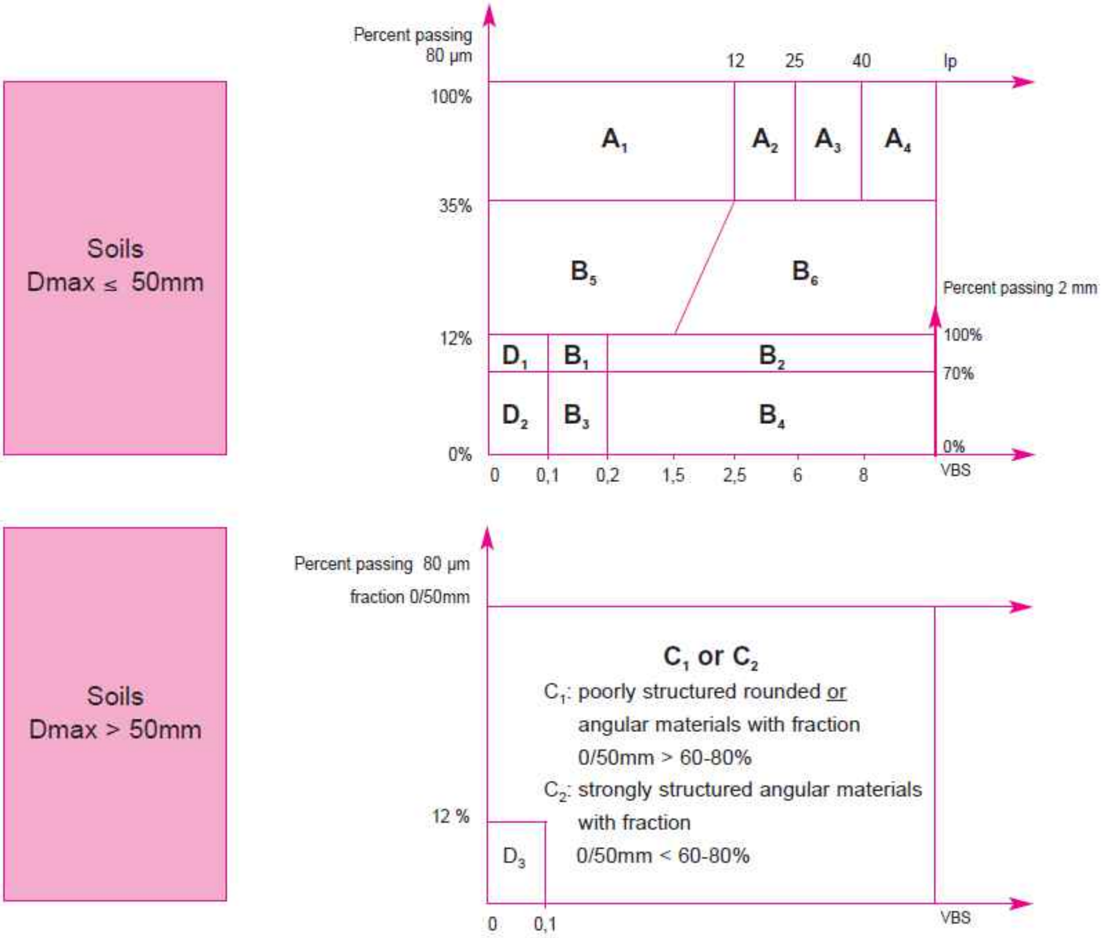
— R_3 class concerns the argillaceous rocks. The scalable nature of these rocks is determined by their fragmentation characteristic (FR test) and their weathering degradability (DG test). The sub-classes go from R_{31} to R_{34}.

— R_4 class concerns the siliceous rocks. The more compact siliceous rocks are classified according to their behaviour under attrition (micro-Deval test and Los Angeles test), while softer rocks are classified according to their fragmentability. The sub-classes go from R_{41} to R_{43}.

— R_5 class concerns the saline rocks. In mechanical terms, this class of materials is like classes R_2 and R_3 but materials are more soluble in water. Critical parameters are fragmentation characteristic and soluble salt content and two sub-classes are defined, R_{51} and R_{52}.

Igneous and metamorphic rocks are considered together in the R_6 class. The more compact rocks are classified according to their behaviour under attrition (micro-Deval test and Los Angeles test), while softer rocks are classified according to their fragmentation characteristic. The sub-classes go from R_{61} to R_{63}.

The French classification of soils and rocks for earthworks is summarized in Figure C.2. Symbols C_1 and C_2 are not used alone. They are added to another symbol from the A or B series: for example, C_1A_3.



Rocks	Sedimentary rocks	Carbonate rocks	Chalk	R_1
			Limestone	R_2
		Argillaceous rocks	Marls, claystone, pelite, etc.	R_3
		Siliceous rocks	Sandstone, puddingstone, breccia, etc.	R_4
		Saline rocks	Rock salt, gypsum, etc.	R_5
	Igneous and metamorphic rocks	Granite, basalt, andesite, gneiss, schist, slate, etc.		R_6

Figure C.2 — French classification of soils and rocks for earthworks (NF P 11-300)

C. Organic soils and industrial by- or co-products group

This category (class F) concerns specific materials which may prove interesting from a technical and economic point of view when used in embankments and capping layers, if they are acceptable with respect to the environment.

There are nine families. The F_1 sub-class concerns the natural materials containing organic matter. The F_2 sub-class concerns the silica-aluminous airborne dusts from thermal power plants. The F_3 sub-class concerns the coal schist. The F_4 sub-class concerns the schist from potash mines. The F_5 sub-class concerns the phosphogypsum. The F_6 sub-class concerns the clinkers or the slags resulting from incineration of household waste. The F_7 sub-class concerns the demolition wastes. The F_8 sub-class concerns the blast-furnace slags. And the F_9 sub-class concerns the other wastes and industrial by- and co-products.

For each sub-class, the possibility of use depends on specific parameters.

In addition to technical issues, these materials are concerned by environmental ones. These issues are discussed in a Guide "Acceptability of alternative materials in road construction – Environmental assessment" (SETRA, 2011).

The first parameter is the type of layer and type of covering (permeable material or natural soil). The study of these polluted materials is done gradually, to assess their possibility of use: leaching tests first, then percolation tests or a particular study for those who did not comply with the tests.

These materials cannot be used at a distance less than 30 m of a river, in a karst area, in sensitive areas nor in a catchment area.

C.3 Design of Earthworks

C.3.1 Introduction

As already mentioned, the philosophy of the French GTR system is to identify the nature of the ground (soils, rocks, other materials), then make specific tests to enter classification tables which lead to experience-based instructions for performing works. In case the ground does not fit into the classification system, preliminary full scale tests are performed to validate an execution procedure (material, extraction or compaction process, eventual treatment) which produces the expected earth-structure. This procedure is used to define the work to be done (for method specification or for defining the work process leading to specified end results).

C.3.2 Specification of the mechanical properties to be obtained

The required properties of the earth structure are defined at the level of the road support platform (PF) and are linked to the pavement design (in case of road construction). Four classes of platforms are used in France, as indicated in Table C.1. Class PF2 was subdivided in 2014, by adding a new threshold 80 MPa. Future documents will have five classes: PF1, PF2 (50-80 MPa), PF2qs (80-120 MPa), PF3 and PF4.

Table C.1 — Classes of road support platforms (PF)

Deformation modulus E_{v2}	20–50 MPa	50–120 MPa	120–200 MPa	> 200 MPa
Class of PF	PF1	PF2	PF3	PF4

The attainable PF class is derived from the properties of the upper part of the fill (PST) and the resulting AR class, and from the capping layer design (C.3.5). These depend on the classification of the materials, their hydric state and the drainage. There are 7 classes of PST (Table C.2) and 5 classes of AR (Table C.3).

Table C.2 — Definition of PST classes

PST case	Types of materials	Comments
PST n° 0	A, B_2, B_4, B_5, B_6, C_1 in a very humid hydric state (th)	Peaty, swampy or flood zones. The deformability may be very high at some moments of the construction or life of the road.
PST n° 1	A, B_2, B_4, B_5, B_6, C_1, R_{12}, R_{13}, R_{34} and some C_2, R_{43} and R_{63} in a humid hydric state (h)	PST made of water sensitive materials with high deformability during the installation of the capping layer and with no later improvement.
PST n° 2	A, B_2, B_4, B_5, B_6, C_1, R_{12}, R_{13}, R_{34} and some C_2, R_{43} and R_{63} in a medium hydric state (m)	PST made of water sensitive materials with good stiffness during the installation of the capping layer, with a possible lowering of this stiffness in case of water infiltrations.
PST n° 3	Same materials as for PST n° 2	PST made of water sensitive materials with good stiffness during the installation of the capping layer, with a possible lowering of this stiffness in case of water infiltrations.
PST n° 4	Same materials as for PST n°1, provided that their particle size allows for treatment	PST made of water sensitive materials, improved with lime or hydraulic binders on 0,30 to 0,50 m thickness.
PST n° 5	B_1, D_1 and some rocky materials of class R_{43}	PST made of sandy materials, insensitive to water, above the water table, with trafficability problems.
PST n° 6	D_3, R_{11}, R_{21}, R_{22}, R_{32}, R_{33}, R_{41}, R_{62}, and some materials from classes C_2, R_{23}, R_{43} and R_{63}	PST made of gravelly or rocky materials, insensitive to water, but with levelling or trafficability problems.

Table C.3 — Definition of AR classes

AR classes	AR0	AR1	AR2	AR3	AR4
Deformation modulus	< 20 MPa	20 MPa	50 MPa	120 MPa	200 MPa

The hydric states are defined in C.3.3.

The correspondence between PST classes and AR classes is shown in Table C.4. The correspondence between AR classes and PF classes is shown in C.3.5 (Table C.7)

Table C.4 — Link of PST classes and AR classes

PST	Possible AR	Comments
PST n° 0	AR 0	Such zones need to be improved (substitution and/or drainage) to allow to reevaluate the AR class to at least AR 1.
PST n° 1	AR 1	In this case, two solutions: either improve the upper part of the material (at least 0,5 m) by lime treatment (to obtain AR 2, 3 or 4), or make a thick capping layer using granular materials, insensitive to water.
PST n° 2	AR 1	A capping layer is generally necessary. In case of ground water lowering at sufficient depth, see PST 3.
PST n° 3	AR1 or AR2	AR 1, similar to PST n° 2, in the absence of drainage of the pavement base and sealing of the AR. AR 2 in case of drainage of the pavement base and sealing of the AR.
PST n° 4	AR 2	The need for a capping layer depends on the project and on the measured values of the bearing capacity of the treated material.
PST n° 5	AR 2 or AR 3	The selection of AR2 or AR3 depends on the nature of materials and the measured value of E_{V2}. Short-term and long-term stiffness values are equal. No capping layer is usually needed except for trafficability.
PST n° 6	AR 3 or AR 4	The selection of AR3 or AR4 depends on the nature of materials and the measured value of E_{V2}. Short-term and long-term stiffness values are equal. No capping layer is usually needed except for levelling and short-term trafficability. A levelling layer may be sufficient.

C.3.3 Classification of hydric state of materials and weather conditions

To specify the execution procedure for embankment construction, the French rules consider two main factors:

a) weather conditions during the embankment construction. Provisions should be made for favourable and unfavourable conditions depending on the season during which the earthworks start (this shall be noted in the risk analysis document);

Four possibilities are considered in the classification tables:

- heavy rainfall: symbol used ++;
- light rainfall: symbol used +;
- weather conditions free from any significant rainfall or evaporation: symbol used =;
- weather conditions causing significant evaporation: symbol used -;

b) water sensitivity and water content (state characteristics) of the material. In fact, there are two main types of materials (soils or rocks), those which are water-sensitive and the others. This sensitivity is defined on the basis of clay activity (percentage below 80 µm and methylene blue value or plastic index I_P).

To define the state characteristics (the water content), one needs:

— the value of the soil consistency index I_c;

— the soil IPI value;

— the natural water content (w_n) at a given time, in relation to the optimum water content (w_{OPN}) determined from the standard proctor test on the fraction smaller than 20mm.

— The only exception for defining the hydric state is made for chalk, for which the hydric state is defined from the dry density and the moisture content.

Five hydric states are considered (Figure C.3):

— the normal state (m) is the best condition for placement ; in particular, it allows appropriate compaction to be achieved;

— the wet (h) and very wet (th) states indicate soils for which trafficability and compaction are difficult (a very wet soil is not normally trafficable for a standard earthmoving plant);

— the dry (s) and very dry (ts) states correspond to soils which are difficult to compact to form stable fill structures: with these kinds of soils the compaction energy has to be adapted. But this is outside of the GTR recommendations, which only consider compaction energies similar to those required in the Normal Proctor test.

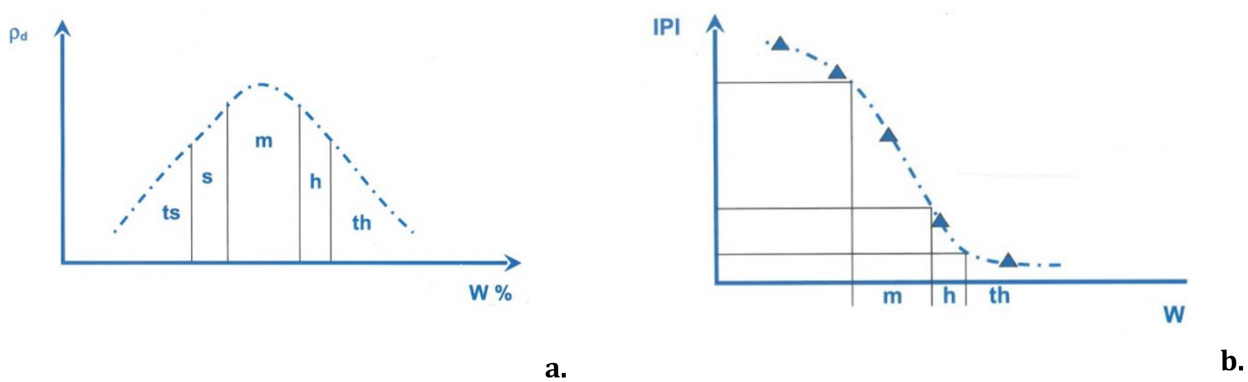


Figure C.3 — Hydric states

C.3.4 Fill material

The GTR prescribes, according to the materials classification and their hydric state, and depending on the weather expected during the earthworks, the conditions in which these materials may or may not be used in the embankment. These conditions depend on various factors, namely:

— extraction: in layer or front loading;

— granularity: disposal of some granular categories (above 800 mm or 250 mm) or complementary fragmentation after extraction;

— moisture correction: this is to add water (humidification or watering) or to dry the material (aeration, wringing);

— treatment: with lime or other suitable reagent;

— layer thickness: thin or moderate (20-30 cm or 30-50 cm or any);

— compaction: weak, average, intense;

— height of the embankment : less than 5 m, 5 – 10 m, more than 10 m.

The treatment of materials using lime or hydraulic binders is defined in a Guide "Treatment of soils with lime or hydraulic binders for embankments and capping layers" – GTS (SETRA/LCPC, 2000).

The treatment of a material with binders consists in mixing, more or less thoroughly, the material with lime, or hydraulic binder, or both of them, and optionally with additional water. The objective is to enhance the properties of materials (soils) with poor characteristics in earth structures.

Two aims can be developed for studies and works:

- soil improvement: reducing water content in the soils for reusing them in the embankments; the mixing of soils and lime (generally), or soils and hydraulic binders, shall lead to a water content between normal and wet states;

- soil stabilization: improving mechanical properties by mixing of soils and lime, or soils and hydraulic binders, or both of them, to improve specified parameters like:

  - CBR after immersion > immediate bearing index for embankment concerned by area liable to flooding = resistance to water;

  - cohesion and internal friction of the soils, for embankment stability;

  - compressive strength for high embankments and technical embankments;

  - modulus of elasticity and tensile strength for capping layers, etc.

— Soil improvement

In this case, the addition of a binder is aimed at improving the physical properties of the soil (short-term), or, more generally, a material, such as water content, plasticity, water and frost susceptibility, compactibility and swelling potential. The quantity of binder added may not be sufficient to induce significant permanent properties.

— Soil stabilization

The aim of soil stabilization consists in obtaining an homogeneous mixture of soil with binder(s), and optionally with water, which, when properly compacted, significantly changes (generally in the medium or long-term) the characteristics of the soil in a way that renders it stable, particularly with respect to the action of water and frost. It creates a permanent behaviour, which can be measured by methods typical of solid materials.

The methods used to study soil treatment are listed in the GTS guide (SETRA/LCPC, 2000).

The first step is to search for soils characteristics, which could hinder or exclude the existing treatment techniques (feasibility):

- soils with blocks. The feasibility of treatment depends on the D_{max} and number of the blocks. For stabilization, D_{max} is generally smaller than 100 to 150 mm, depending on the equipment. Treatment with lime or hydraulic binders concerns in generally soils (D_{max} < 50 mm) or soils with blocks in minority (class C_1);

- any constituent in the soils which would adversely affect setting, hardening, performance and volumetric stability of the treated material (organic matter, soils with sulfur, sulfide, sulfate, etc.

This part of the study is generally done by experienced geotechnical engineers.

Then, for soil improvement, the studies consist in laboratory tests to determine for the mixture (soils and binders): Proctor references, immediate bearing index with objectives giving by GTS, CBR after immersion when resistance to water is needed.

For soil stabilization, the second step is to determine the suitability for treatment, using accelerated swelling tests (NF P 94-100).

This test should take place at the earliest possible stage in the project to identify any risks of swelling or setting failure. This study shall determine the indirect tensile strength (R_{it}) and volumetric swelling. The suitability for treatment is given in Table C.5 for soils with hydraulic binder and in Table C.6 for soils with lime only.

Table C.5 — Criteria for interpreting suitability for treatment for soils with hydraulic binder

Soils with hydraulic binder	Volumetric swelling G_v (%)	Tensile strength after 7 days conservation in water R_{it} (MPa)
Suitable	$G_v < 5$ % and	$R_{it} > 0,2$ MPa
Doubtful	5 % $\leq G_v \leq$ 10 % or	0,1 MPa $\leq R_{it} \leq$ 0,2 MPa
Unsuitable	$G_v > 10$ % or	$R_{it} < 0,1$ MPa

Table C.6 — Criteria for interpreting suitability for treatment for soils with lime only

Soils with only lime	Volumetric swelling G_v (%)	Tensile strength after 7 days conservation in water R_{it} (MPa)
Suitable	$G_v < 5$ %	No value
Doubtful	5 % $\leq G_v \leq$ 10 %	
Unsuitable	$G_v > 10$ %	

Additional tests like CBR after immersion, compressive strength (R_c), cohesion and internal friction, can be realized. The aim is to analyse specifics properties in the medium or long-term.

Criteria for technical (next to structures) embankments, high embankments, upper part of earthworks (PST), etc. are given in the GTS. For example, for a high embankment, GTS recommends to obtain a compressive strength larger than 0,5 or 1 MPa (depending of the height of embankment).

Finally, the treatment study can determine long-term modulus and tensile strength (28 days – 90 days or 180 days) to be used for designing capping layers made of materials treated with hydraulic binders.

C.3.5 Capping layer

For the materials used in capping layers, the French rules consider the hydric state of the material, the weather expected during the earthworks, and the PST/AR couple classification. With these data, the GTR indicates the possibility for re-use of materials, the thickness of the capping layer, how the capping layer should be constructed and the platform class (PF1 to PF4) that will be obtained. In particular, the following can be selected:

— the granularity according to the water sensitivity, by carefully adjusting the mixing used in the layer;

— the water content correction;

— the treatment : the use of lime or other binders will make some very humid (th) soils suitable for use as capping layer material. A special study shall always be made to determine the benefits and feasibility of treatment, application rates, and associated difficulties if they exist;

— the protective measures : protective coating, etc.

If the chosen capping layer is thinner than the thickness recommended in the GTR tables, the PF class is kept the same as the AR class. If it is thicker, the PF class may be increased.

Three cases are considered:

— capping layer made of untreated granular material. With some kinds of material, the PF3 class will be obtained directly, with adequate capping layer thickness (Table C.7).

Table C.7 — Example of specifications for capping layer made of untreated granular material

AR class	PF class	Material used	Capping layer thickness
AR1	PF3	B_{31}, C_1B_{31}, C_2B_{31}, D_{21}, D_{31}, R_{21}, R_{41}, R_{61} C_1B_{11}, C_2B_{11}, R_{11}, R_{42}, R_{62} (provided the PF stiffness is checked)	0,80 m (a reduction of 0,10 to 0,15m may be accepted in case an adequate geotextile is put between the PST and the capping layer)
AR2	PF3	The same as above	0,50 m

— capping layer made of lime or cement treated clayey soils, treated *in situ*. The PF3 class above AR1 or AR2 will then be obtained directly, when following the indications of Table C.8.

Table C.8 — Example of specifications for capping layer made of treated clayey soil

AR class	PF class	Material used	Capping layer thickness
AR1 (for PST 2 and PST 3 only)	PF3	A_3 treated with lime, only	0,70 m (in two layers)
		A_1, A_2, A_3 treated with lime+cement or eventually cement alone	0,50 m (in two layers)
AR2	PF3	A_3 treated with lime, only	0,50 m (in two layers)
		A_1, A_2, A_3 treated with lime+cement or eventually cement alone	0,35 m

— capping layer made of hydraulic binder treated materials. The expected PF class above AR1 or AR2 is defined in Table C.9, on the basis of the mechanical class of the treated material and the thickness of the capping layer.

Table C.9 — Specifications for capping layer made of materials treated using hydraulic binder

AR class		AR1			AR2	
		Thickness of the capping layer				
Mechanical class of the treated material used	3	< 30 cm	30 cm	40 cm	25 cm	30 cm
	4	30 cm	35 cm	45 cm*	30 cm	35 cm
	5	35 cm	50 cm*	55 cm*	35 cm	45 cm*
PF class obtained		PF2	PF3	PF4	PF3	PF4
* two layers will usually be needed to obtain the required compacity at the bottom of the capping layer						

The definition of the mechanical class of the materials treated with hydraulic binders is based on direct traction strength R_t and deformation modulus E obtained from tests on treated material, after 90 days maturation. The values of R_t and E are put on the diagram of Figure C.4, which defines five zones. The zone in which R_t and E are located is used to define the mechanical class, depending on whether the treatment will be done in place or in a plant (Table C.10).

Table C.10 — Definition of the mechanical class of materials treated with hydraulic binders

Treatment in plant	Treatment in place	Mechanical class obtained
Zone 1	Zone 1	1
Zone 2	Zone 2	2
Zone 3	Zone 3	3
Zone 4	Zone 4	4
Zone 5		5

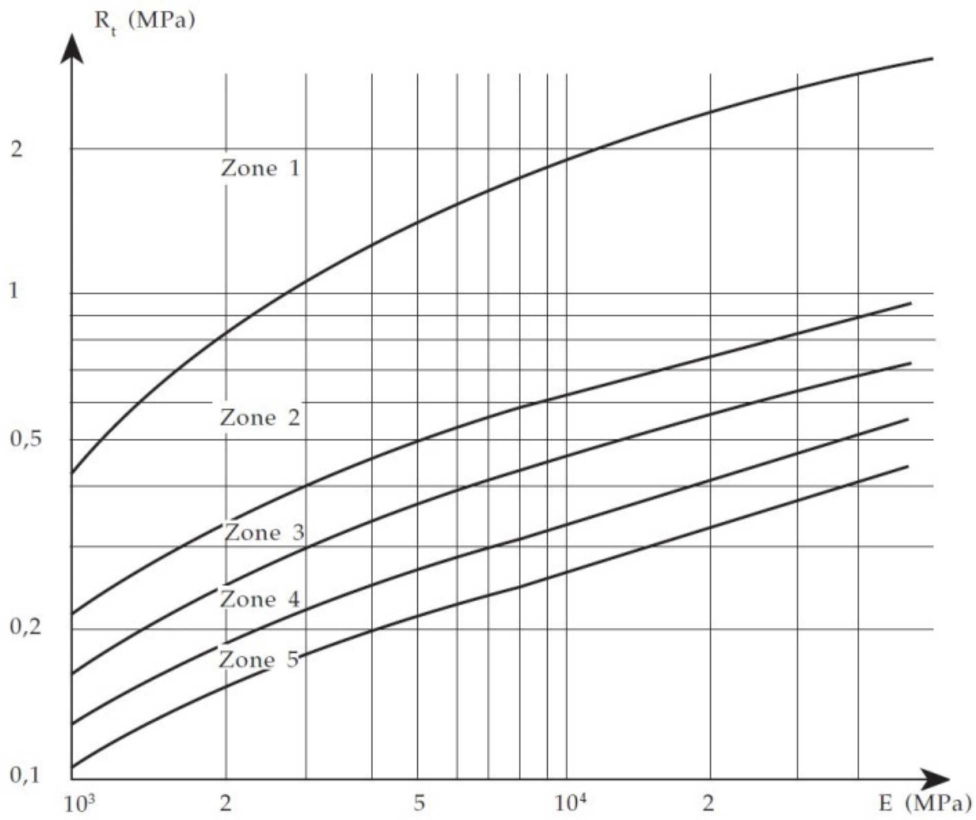


Figure C.4 — Zones of mechanical properties for materials treated with hydraulic binders

C.3.6 Compaction of fill

The GTR recommendations, once the conditions in which the materials may be used are defined, indicates the compaction energy needed to achieve the densification objectives.

The GTR classification system, according to nature (intrinsic properties) and state of materials, describes soil classes such that, within each class, the densification energy needed to obtain a stable fill is roughly the same. In this way, the compaction energy can be set beforehand for each specific job, along with appropriate construction method.

The required compaction energy is expressed by two parameters:

- maximum thickness (compacted thickness, not bulk thickness) of constituent layers of fill;

- Q/S ratio in m^3 per m^2, a measure of the ratio between the compacted soil volume placed in a given time (say, one day) Q, and the area of fill covered by the compaction machine in the same time S. Volume Q is calculated from the number of round trips by haulage plant of known capacity or beforehand from the estimated geometrical volume of the embankment to calibrate the haulage plant. Area S is obtained from the effective width of the compaction machine multiplied by the distance covered by the machine, usually read from the mileage counter or, better, from a tachograph fitted to the machine.

The next step is to classify the compaction plant according to its performance. This classification refers to French standard NF P 98-736. Its basic principles are set forth below:

— the rollers considered have a compaction width of 1,30m or more;

— the basic types of compacting plant addressed are:

— pneumatic tyred rollers Pi;

— smooth vibrating drum rollers Vi;

— tamping rollers VPi;

— static tamping rollers SPi;

— vibrating plate compactors PQi;

— i is the class number; it increases with compaction efficiency within each type category.

The final step of the GTR method is to fix the number of load applications for a given material, a given plant, a given compacted thickness and a given speed of the plant. This information is given in tables, given for each class of material. Figure C.5 shows an example of compaction specifications for material classes A_2 and C_1A_2.

A_2, C_1A_2 (*)

Compacteur / Modalités		P1	P2	P3	V1	V2	V3		V4		V5		VP1	VP2	VP3	VP4	VP5	SP1	SP2	PQ3	PQ4
	Q/S	0.030	0.050	0.070		0.035	0.050		0.065		0.080			0.035	0.065	0.090	0.105	0.035	0.060		
	e	0.20	0.25	0.35		0.20		0.30	0.30	0.40	0.30	0.45		0.20	0.30	0.30	0.30	0.20	0.30		
Energie de compactage moyenne					0								0	(2)	(2)	(2)	(2)	(2)	(2)	0	0
	V	5.0	5.0	5.0		2.0		2.0	2.5	2.0	3.0	2.0		2.0	2.0	2.5	3.0	3.0	3.0		
Code 2	N	7	5	5		6		6	5	7	4	6		6	5	4	3	6	5		
	Q/L	150	250	350		70		100	165	130	240	160		70	130	200	315	280	480		

* D_{max} shall be less than 2/3 of the compacted layer

Notes: Q/S (m), layer thickness e (m), roller speed V (km/h), number of passes N (-), Q/L ($m^3/h/m$)

(2) plan an additional operation to erase the prints in case of predicted rain after the work (take off the upper centimetres or use another type of compacting plant)

0 – compaction plant is not adequate

Figure C.5 — Example of GTR recommendations for compacting A_2 and C_1A_2 soils

C.3.7 Extraction and transportation of soil and rocks

The recommended techniques are summarized in Table C.11 (for fine materials) and Table C.12 (for rocky materials).

Table C.11 — Extraction and transportation of fine soils

Excavation (with or without stockpiling)	Shovel excavator or front loader			Motorscrapers
Transportation	Articulated dump truck	Rigid dump truck	Road lorry	
Haul road	Deformable	Slightly deformable	Non deformable	Slightly deformable
Distance	Short distance (<3000 m)	Long distance (<5000 m)	Long distance (>5000m)	Short distance (<1500 m)

Table C.12 — Extraction and transportation of rocky materials

Excavation	Ripper or Blasting	
Loading	Shovel excavator or front loader	
Transportation	Articulated dump truck	Rigid dump truck
Haul road	Deformable	Slightly deformable
Distance	Short distance (2000 m)	Long distance (<5000 m)

C.3.8 Compaction of materials

Suitable equipment for various types of materials are indicated in Table C.13.

Table C.13 — Summary of suitable compaction equipment

Compaction equipment	Wheeled roller	Vibratory smooth roller	Vibratory tamping roller	Deadweight tamping roller	Vibrating plate compactor
Fine silty or clayey soils with less than 30 % of particles > 50mm	possible	adapted	adapted	adapted	non adapted
Fine silty or clayey soils with blocks	possible	adapted	possible	possible	possible
Sandy gravels	possible	adapted	non adapted	non adapted	possible
Strong rocks	possible	adapted	non adapted	non adapted	possible
Evolutive rock and chalk	possible	adapted	possible	possible	possible

C.4 Control of earthworks

C.4.1 Introduction

This clause describes:

— the actions and current practices in France for monitoring the execution of earthworks;

— the ways and procedures to check this execution.

Two kinds of controls are implemented:

— controls by tests and trials; these are defined by their type and frequency;

— controls by visual observations; these visual checks shall be done by a skilled officer.

C.4.2 Technical processes and control methods

C.4.2.1 Identification of materials

Before the beginning of the earthworks in the field, materials are identified (as described by GTR). The conditions for their reuse, as a function of their hydric state, are then defined.

During the construction operations, the hydric state of the materials shall be checked day by day.

From time to time, a check of the maximal grain size and clay activity can be done to ensure the homogeneity of the deposits from which materials are extracted.

<u>Relevant standardized tests for identification of materials</u>

Particle size analysis NF P94-056

Water content NF P94-050

Atterberg’s limits NF P94-051

Methylene blue absorption capacity NF P94-068

Compaction test (Proctor tests) NF P94-093

CBR after immersion - Immediate CBR - Immediate bearing ratio NF P94-078

Fragmentability coefficient of rocky material NF P94-066

Degradability coefficient of rocky material NF P94-067

Resistance to fragmentation (Los Angeles) NF EN 1097-2

Resistance to wear (Micro-Deval) NF EN 1097-1

Sand friability coefficient NF P 18-576

Particle density NF P 94-054

Density of a dehydrated rock sample NF P 94-064

Water reactivity for quick lime NF P 98-102

C.4.2.2 Preparation of materials

— Actions on the hydric state;

For the materials that are too dry, the water content can be increased by spraying to bring it up closer to the optimum water content (w_{OPN}).

For materials that are too wet, the water content can be decreased by mechanical aeration or lime treatment.

— Actions on particle size distribution;

The maximum particle size of materials shall be relevant to the thickness of the layer and its required characteristics.

In all cases, blasting shall be rationalized to avoid, as far as possible, further processing of the rocky materials. After blasting, actions on particle size can be:

— sorting after quarrying;

— screening of rough materials;

— crushing of materials;

— use of hydraulic rock breaker to comminute blocks.

For the capping layers, if a central crushing station is used, rates and storage areas shall be integrated in the project.

The check of these actions is usually visual, but measurements of water content and particle size can be done.

C.4.2.3 Earthmoving program

It is important to ensure that the earthmoving program in the field is consistent with the project. The monitoring can be done by means of the compaction checks.

C.4.2.4 Compaction

Compaction aims at ensuring a minimum required density to avoid long-term settlements and to reduce the voids ratio.

• Long-term settlements

The method used in France to measure the compaction levels is called the “e-Q/S” method. For a given thickness e of a compacted layer, the ratio Q/S (m^3/m^2) between the compacted material volume Q and the covered surface S. This couple (e, Q/S) is then compared with theoretical values.

Checks on compaction can be:

— check of the compaction tools and the compliance with the contract documents;

— check of the harmony between compaction tools and rates of implementation;

— check of the recorded Q/S on compactors;

— check of relevant distribution of compaction and the compliance with the layer thickness.

In addition, further measurements can be done:

— density measurements;

— for granular materials, measurements with a dynamic penetrometer to check the layer thickness and consistency of compaction.

- Decrease of the void ratio

The inherent features of the materials (cohesion and angle of internal friction) increase when the void ratio decreases. For the improvement of the mechanical features of cement-treated soils, it is more frequent to adjust the dosage in cement to reach the aimed performances, than to increase the density. This last solution is possible, but subject to realizing a full scale test.

<u>Relevant standardized tests for compaction control</u>

Measurement of mechanical features on drill cores:

compressive strength: NF EN 13286-41;

modulus of elasticity: NF EN 13286-43;

diametral compression test: NF P 98-232-3.

Determination of density of materials on site - gammadensitometer: NF P 94-061-1

Determination of density of materials on site - Method for large materials: NF P 94-061-4

Measurement of density on site - Gamma- gamma ray log: NF P 94-062

Compaction quality control - Constant energy dynamic penetration test method: NF P 94-063

Inspection of compaction quality - Method using a variable energy dynamic penetrometer: NF P 94-105

Compactors. Evaluation of the eccentric moment: NF P 98-761

Pneumatic tyre compactors. Evaluation of the contact pressure on soil: NF P 98-760

C.4.2.5 Deformability

An adequate deformability is needed for the construction traffic. Pavement design is also based on this parameter.

- Deformability for construction traffic

It is required to check that hydric state of materials is relevant for construction traffic.

- Deformability for design

It is required to construct a test section in order to adjust operating parameters and to construct a full-scale reference in order to adjust checking parameters. For granular materials, it is recommended to build a full-scale reference with a high thickness in order to compare the materials modulus and the design modulus.

Measurements of the deformability of the roadbed (PF) and formation level (AR) can be done by means of a plate load test, a Dynaplaque, a deflectograph, a Benkelman beam, or a portancemetre.

For lime/cement treated layers, bearing capacity is measured with a deflectograph or curviameter. For lime/cement treated layers, it is also required to check the amount of used binders. At least two ways can be proposed:

— tarpaulins or trays are placed in the field before the binders spreading. After the spreading, the amount of collected binders is measured;

— axles of the spreading truck are weighted before spreading and after spreading on a defined surface.

Relevant standardized tests for deformability measurement

Formation level bearing capacity - Part 1: Plate test static deformation module (E_{V2}): NF P 94-117-1

Formation level bearing capacity - Part 2: Dynamic deformation module: NF P 94-117-2

Measurement of a rolling load deflection: NF P 98-200-1, 2, 3, 4 and 7

C.4.2.6 Drainage

- Construction drainage

The aim of construction drainage is to allow the evacuation of run-off waters (precipitation and intercepted groundwater).

Attention shall be paid to:

— cross-sections and longitudinal sections have to allow rational run-off;

— avoid crossing water outfall during cuttings;

— protect the top of the earthworks by compaction;

— building of temporary ditches;

— collection of groundwater.

- Permanent drainage

During construction process, compliance checks between earthworks and project shall be done.

After works, the efficiency of drainage shall be checked.

C.4.2.7 Geometrical setting out of the works

Non respect of project layout can lead to costly rework. The Land surveyors marks shall be respected. Furthermore, the widths of platforms, embankment slopes and altimetry of structure shall be checked.

— Environment

The aim is to minimize the impact of earthworks on the environment. It is important to avoid soaring of dust or soaring of dry cement. Trucks and other earthworks vehicles shall be cleaned in a dedicated place. All waters from construction site have to decant before salting out in the environment. Vibrations resulting from mining or from compaction and noise shall be limited.

For these points, the checks are visual, but some measurements can also be done.

— Specific building methods

For these works, the recommendations specific to these techniques shall be followed.

C.5 References

AFNOR (1992). NF P 11-300 : Exécution des terrassements. T2: Classification des matériaux utilisables dans la construction des remblais et des couches de forme d'infrastructures routières.

SETRA (2007). Conception et réalisation des terrassements – Guide technique.

Fascicule 1: études et exécution des travaux.

Fascicule 2: organization des contrôles.

Fascicule 3: méthodes d'essais.

The English translation of this document is available and can be downloaded from the Cerema website.

SETRA (2007) Design and execution of earthworks.

Section 1: Design and execution of work.

Section 2: Organization of checks.

Section 3: Test procedures.

SETRA (2011). Acceptabilité de matériaux alternatifs en technique routière – Évaluation environnementale – Guide méthodologique.

SETRA-LCPC (1992-2000). Réalisation des remblais et des couches de forme – Guide technique.

Fascicule 1: Principes généraux.

Fascicule 2: Annexes techniques.

An English abbreviated version of this document is available and can be downloaded from the Cerema website.

LCPC (2003). Practical manual for the use of soils and rocky materials in embankment construction.

SETRA-LCPC (2000). Traitement des sols à la chaux et/ou aux liants hydrauliques – Application à la réalisation des remblais et des couches de forme – Guide technique.

SETRA-LCPC (2007). Traitement des sols à la chaux et/ou aux liants hydrauliques – Application à la réalisation des assises de chaussée – Guide technique.

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SETRA (2008). Treatment of soils with lime and/or hydraulic binders – Application to the construction of pavement base layers.

SETRA (2006). Drainage routier – Guide technique.

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SETRA (2007). Road Drainage.

SETRA-LCPC (2000). Organization de l'assurance qualité dans les travaux de terrassements – Guide technique.

CFTR (2002). Terrassements à l'explosif dans les travaux routiers – Guide technique.

Tests standards listed in the text.

Annex D
(informative)

Summary of national practice - Germany

D.1 Introduction

Earthwork regulations in Germany are based on standards and special specifications of public clients. The standard for the definition of soil groups is DIN 18196 *Erd- und Grundbau – Bodenklassifikation für bautechnische Zwecke (Earthworks and foundations, Soil classification for civil engineering purposes).*

The soil groups are defined by the intrinsic properties. Clause D.2 of this annex explains the system of classification with soil groups. Clause D.3 shows their use for planning and processing earthworks in road, railway and waterway construction.

For the choice of the earthworks machinery and for the way of the execution of the earthworks, the given ground material shall be classified together with defined state parameters, in order to enable the design of the earthwork procedures. The required information about the given soil conditions are specified in:

DIN 18300 *VOB Vergabe- und Vertragsordnung für Bauleistungen – Teil C: Allgemeine Technische Vertragsbedingungen für Bauleistungen (ATV) – Erdarbeiten (VOB Construction contract procedures – Part C: General technical specifications in construction contracts (ATV) – Earthworks).*

DIN 18300 contains a list of parameters of soil and rock. The range of the values of these parameters shall be determined by means of laboratory and field tests. It applies to loosening, loading, conveying, placing, compacting and treatment - if necessary - of soil and rock.

Specific regulations for earth-structures and earthworks in road construction are given by:

Zusätzliche Technische Vertragsbedingungen und Richtlinien für Erdarbeiten im Straßenbau, ZTV E-StB 09 (Additional Technical Terms of Contract and Guidelines for Earthworks in Road Construction),

for waterway construction by:

Zusätzliche Technische Vertragsbedingungen – Wasserbau, ZTV-W (Additional Technical Terms of Contract for earth structures of waterways)

and for earth structures of railways by:

Ril 836 Erdbauwerke und sonstige geotechnische Bauwerke planen, bauen und instandhalten (Planning, Building and Maintaining of earth structures and other geotechnical structures)

of the DB Netz AG.

ZTV E-StB contains contractual regulations for the realization of earthworks in road construction, requirements for compaction and bearing capacity, soil treatment, internal control (self monitoring) of the Contractor and compliance testing as well as for reporting duties. The test specifications in earthworks are described in:

Technische Prüfvorschriften für Boden und Fels im Straßenbau, TP BF-StB (Technical Testing Regulations for Soil and Rock in Road Construction).

ZTV-W contains contractual regulations for the realization of earthworks for waterways and requirements for earth structures on waterways.

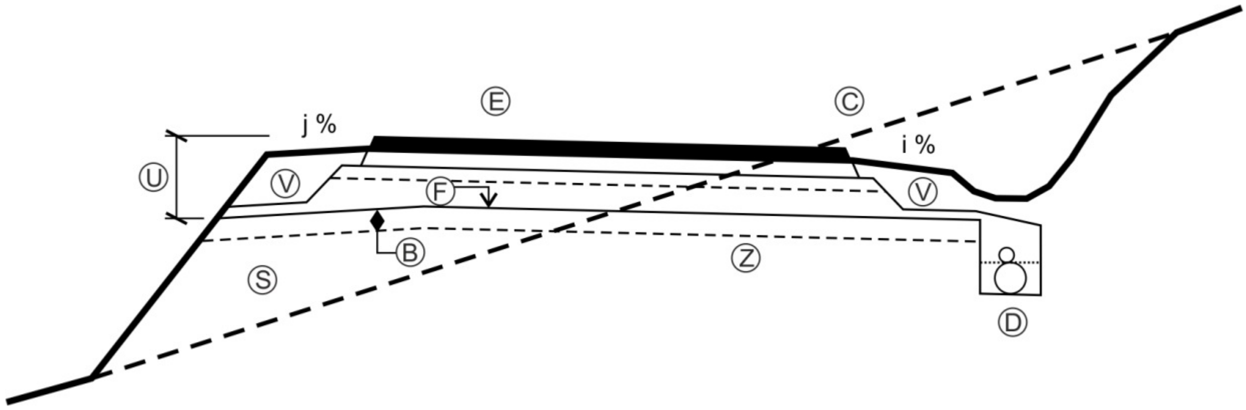
The Ril 836 contains the relevant specifications for railways in Germany. They refer as far as possible to the ZTV E-StB.

Since increasingly processed soil material and other adequate mineral building materials are delivered for earthworks the

Technische Lieferbedingungen für Böden und Baustoffe für den Erdbau im Straßenbau, TL BuB E-StB (Technical Delivery Specifications for Soils and Building Materials for Earthworks in Road Construction)

have been compiled for this scenario. Essentially, they contain requirements for the composition according to the soil groups described in D.2, for the adjustment of the acceptable water content range and for environmentally relevant criteria.

Specific terms and definitions for road constructions are shown in Figure D.1.



Key

B substructure/base

C cut/side cut

D roadside drainage facilities

E embankment

F formation level

S substructure

U superstructure

V verge

Z subsoil

Figure D.1 — Embankment/cut (scheme) for roads

D.2 Classification of materials

D.2.1 Classification according to DIN 18196

D.2.1.1 General

For the purposes of DIN 18196, the terms and definitions of EN ISO 14688-1 and EN ISO 14688-2 apply.

DIN 18196 defines a system of soil groups based on intrinsic properties as proposed in EN 396 Part 2, Clause 5.2 without further state properties. The parameters to determine soil groups are:

- particle size distribution;
- plasticity;
- organic content.

The subdivision of soil groups is developed to summarize soil types with similar engineering properties depending on water content and compactness. Examples of qualitative assessment of the engineering parameters for the different defined soil groups are given in the standard.

The classification system is derived for naturally sedimented soil, but can be used also for reused material as crushed rock if grain strength properties are considered additionally. The maximum grain size considered is 63 mm. Larger blocks for use in earthworks are at present not classified.

DIN 18196 is used as basis for specifications of public clients like road, railway or waterway organisations. Together with compaction requirements, the soil groups accepted in defined zones of an earth structure ensure sufficient properties of strength and stiffness and other parameters for the intended use of the structure. Together with other design parameters e.g. inclination of slope, dewatering measures, limitation of height and external loads, the material and compaction requirements replace further approvals by calculations of bearing capacity/stability and serviceability in standard cases.

D.2.1.2 Characteristics

Fractions

In soil classification, only particle sizes up to 63 mm are considered.

If coarse material (particle size of more than 0,063 mm) forms more than 95 % by mass of the soil material, classification is based on the particle size distribution.

If fine material (particle size 0,063 mm or less) forms 40 % by mass or more of the soil material, classification is based exclusively on the plastic properties of the soil.

In the case of soils composed of both coarse and fine material (with 5 % to 40 % by mass of fines in soils of particle size smaller than 63 mm), classification is based on both particle size distribution and plastic properties.

Particle size distribution (grading)

For the classification of coarse soils and composite soils, their dominant fraction is established in accordance with Table D.1.

Table D.1 — Main groups on the basis of the dominant fraction

Dominant fraction	**Symbol**	**Percentage of particles ≤ 2 mm**
Gravel	G	Up to 60
Sand	S	Over 60

Coarse soils are classified additionally in accordance with Table D.2 and Figure D.2, considering the uniformity coefficient and the index of curvature.

Table D.2 — Grading of coarse soils as a function of uniformity coefficient C_U and index of curvature C_C

Term	**Symbol**	**C_U**	**C_C**
Uniformly graded	E	< 6	Any
Widely graded	W	≥ 6	1 to 3
Gap graded	I	≥ 6	< 1 or > 3

Composite soils (mixed grained soils) are classified additionally in accordance with Table D.3, considering the percentage of fines < 0,063 mm in size.

Table D.3 — Classification of composite soils according to fines content

Grading	**Symbol**	**Percentage of fines up to 0,063 mm**
Low	U or T	5 to 15
High	$\overline{U}$ or $\overline{T}$	over 15 up to 40
Instead of the symbols $\overline{U}$ and $\overline{T}$, U* and T* may be used.		

The group of fine grained soils contains low, intermediate and high plastic silts with the soil groups UL, UM and UA, as well as low, intermediate and high plastic clays with the soil groups TL, TM and TA.

Plastic properties

Fine grained soils are classified according to their position above or below the A-line (i.e. as clay (T) or silt (U)) in the plasticity chart (Figure D.2) depending on liquid limit w_L and plasticity index $I_p = w_L - w_p$ (w_p being the water content at the plastic limit).

For composite soils, the fines fraction is classed as clay or silt, as appropriate. Composite soils are placed into subgroups, as 'clayey' or 'silty' according to the consistency limits w_L and I_p.

Fine and composite soils are classified in accordance with Figure D.2 and Table D.4 according to their plastic properties.

The consistency limits of organogenic fine soils (denoted by O) lie mostly below the A-line.

Composite soils are placed into subgroups, as 'clayey' or 'silty' according to the consistency limits w_L and I_p.

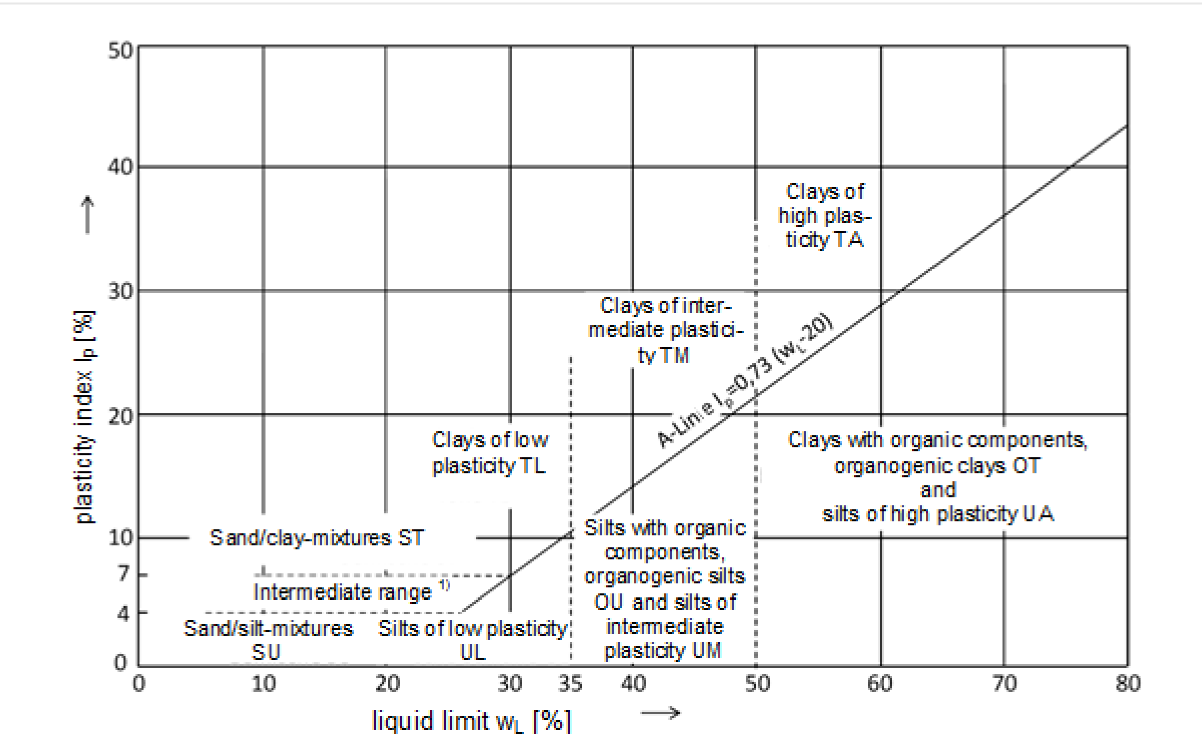


Figure D.2 — Plasticity chart with examples for soil groups

1) Since the plasticity index of soils having a low liquid limit cannot be exactly established experimentally, soils of intermediate plasticity shall be classed as either clay or silt using different methods, e.g. according to EN ISO 14688-1.

Organic constituents

When soils with organic constituents are classified according to their organic matter content, a distinction is made between organic soils (denoted by H or F) and organogenic soils or soils with a high content of organic matter (denoted by O). Dried Soils (denoted by H or F) are combustible and can smoulder in air, whereas soils (denoted by O) do not.

The classification of organic soils is divided into *in situ* accumulations (peat/humus, denoted by H) and mud deposited by water (putrid mud, denoted by F).

Peats are classed according to the degree of decomposition as:

- not decomposed to moderately decomposed (denoted by N); and
- decomposed (denoted by Z).

Made ground

Made ground formed of altered mineral material (denoted by A) are deposits whose original status has been modified by anthropogenic influence.

Anthropogenic deposits are classified as made ground even if they consist of natural inorganic or organic soil material.

The corresponding soil groups are indicated in square brackets (e.g. [GU]).

D.2.1.3 Soil groups

A soil is assigned to a soil group on the basis of Table D.4 and given the symbol specified in the last column. The letter placed first denoting the dominant fraction and the second letter any particular qualifying physical property or the secondary fraction. In general, laboratory tests are conducted to classify soil samples. For civil engineering purposes of the geotechnical category GK 1 according to DIN 4020, visual and manual methods according to DIN EN ISO 14688-1 may be sufficient to identify the soil group.

DIN 18196 includes additional information about characteristics, about the engineering properties like shear strength, compactibility, compressibility, permeability, susceptibility to erosion and susceptibility to frost and about the suitability for possible use of soil groups for foundation soil, unpaved roads, road and railway embankments, impervious elements (seals) of dams, supporting shells of dams and drainage systems.

Table D.4 — Soil classification for engineering purposes

Basic Soil Type	Fraction as percentage by mass Particle size 0,063 mm or less	 2 mm or less	Position with respect to A-line (Figure 3)	Soil groups		Symbol
Coarse soils	Less than 5 %	Up to 60 %	–	Gravel	Uniformly graded gravel	GE
					Widely graded gravel mixtures	GW
					Gap graded gravel mixtures	GI
		Over 60 %	–	Sand	Uniformly graded sand	SE
					Widely graded sand mixtures	SW
					Gap graded sand mixtures	SI
Composite soils	5 to 40 %	Up to 60 %	–	Gravel/silt mixtures	5 to 15 % not exceeding 0,063 mm	GU
					Over 15 up to 40 % not exceeding 0,063 mm	GU *
				Gravel/clay mixtures	5 to 15 % not exceeding 0,063 mm	GT
					Over 15 up to 40 % not exceeding 0,063 mm	GT *
		Over 60 %	–	Sand/silt mixtures	5 to 15 % not exceeding 0,063 mm	SU
					Over 15 up to 40 % not exceeding 0,063 mm	SU *
				Sand/clay mixtures	5 to 15 % not exceeding 0,063 mm	ST
					Over 15 up to 40 % not exceeding 0,063 mm	ST*
Fine Soils	Over 40 %-	–	lp ≤ 4 %, or below A-line	Silt	Silts of low plasticity $w_L < 35$ %	UL
					Silts of intermediate plasticity 35 % ≤ w_L ≤ 50 %	UM
					Highly compressible silts $w_L > 50$ %	UA
		–	lp ≥ 7 %, and above A-line	Clay	Clays of low plasticity $w_L < 35$ %	TL
					Silts of intermediate plasticity 35 % ≤ W_L ≤ 50 %	TM
					Highly compressible silts $W_L > 50$ %	TA

Basic Soil Type	Fraction as percentage by mass — Particle size: 0,063 mm or less	Fraction as percentage by mass — Particle size: 2 mm or less	Position with respect to A-line (Figure 3)	Soil groups		Symbol
Organic Soils, Soils with organic components	Over 40 %	–	lp ≥ 7 %, and below A-line	Non-combustible or non-smouldering	Silts with organic, components and 35 % < w_L < 50 %, organogenic silts	OU
					Clays with organic components, and w_L > 50 %, organogenic clays	OT
	Up to 40 %	–	–		Coarse to composite soils with humic components	OH
					Coarse to composite soils with calcareous or siliceous components	OK
Organic soils	–		–	Combustible or smouldering	Not decomposed to moderately decomposed pests	HN
					decomposed pests	HZ
					Mud, collective term comprising, putrid mud, peaty mud, gyttja, dy and sapropel	F
Made ground	–		–	Made ground of natural material (with relevant group symbol given in square brackets)		[...]
				Made ground of altered or artificial mineral material		[A]

D.2.2 Classification according to DIN 18300

D.2.2.1 Allocation of soil and rock into homogeneous areas

DIN 18300 contains general technical specifications for construction contracts for earthworks. The standard is part of a group of standards for contract procedures. DIN 18300 prescribes a project orientated classification system. It is based on the intrinsic properties and the state properties of soil and rock respectively. The idea is to define homogeneous areas in a given ground with similar properties regarding earthwork procedures using defined types of machinery. The classification of soil according to DIN 18196 is an essential part of the classification according to DIN 18300.

Soil and rock are allocated into homogeneous areas according to their condition before loosening. The homogeneous area is a defined area consisting of single or several soil or rock layers, which has similar characteristics for applicable earthwork. The definition of the homogeneous areas shall consider loosening, conveying, treatment - if necessary - and compaction.

If there are environmentally relevant materials in soils or rock, they shall be respected for the allocation into separate homogeneous areas.

Based on the description of soils according to DIN 14 688-1 homogenous areas will be generated. For these homogeneous areas, the following characteristics and parameters as well as the range of those values shall be stated. If there are several possible procedures for determination, the according standard or specification will be mentioned.

For soil:

- soil groups referring to DIN 18196, additional local description;
- cobble and boulder content referring to DIN EN ISO 14688-2;
- grain size distribution referring to DIN 18123;
- moist density referring to DIN 18125;
- consistency, consistency limit and water content referring to DIN 18121, DIN 18122 and DIN EN ISO 14688-2;
- undrained shear strength referring to DIN 18136, DIN 18137-2 or DIN 4094-4;
- density referring to DIN 18126 or DIN EN ISO 22476-1 and DIN EN ISO 22476-2;
- organic content (ignition loss) referring to DIN 18128.

In case of construction projects of the geotechnical category GK1 referring to DIN 4020, the following information is sufficient: soil groups, cobble and boulder content, consistency, density.

For rock:

- petrography referring to DIN EN ISO 14689-1, additional local description;
- density referring to DIN EN 1997-2;
- discontinuities and spatial orientation referring to DIN EN ISO 14689-1;
- weathering of the rock mass referring to DIN EN ISO 14689-1;
- unconfined compressive strength referring to DGGT-Recommendation No 1.

In case of construction projects of the geotechnical category GK1 referring to DIN 4020, the following information is sufficient: petrography, discontinuities and spatial orientation, weathering.

D.2.2.2 Description and allocation of other material

If possible, other material, e.g. made ground, structure deposit, artificial soil, shall be described referring to DIN EN ISO 14688-1 and DIN EN ISO 14689-1 and allocated referring to D.2.2.1. Is this impossible, the material shall be specifically described with regard to their characteristics for earthworks.

D.2.3 Classification of frost susceptibility of soil groups according to ZTV E-StB

The classification of soil groups regarding their frost susceptibility is carried out according to Table D.5.

Table D.5 — Classification of soil groups according to their frost susceptibility

	frost susceptibility	**soil groups (**DIN 18196**)**
F 1	not frost susceptible	GW, GI, GE SW, SI, SE
F 2	low to medium frost susceptible	TA ST[1)], GT[1)] SU[1)], GU[1)] amongst others
F 3	very frost susceptible	TL, TM UL, UM, UA ST*, GT*, SU *, GU* amongst others

[1)] under certain conditions related to F1

D.3 Execution of earthworks

For the execution of earthworks, each working technique which enables the achievement of the requirements without noxious impact to the environment can be used. The working technique depends on the soil to be loosened, loaded, conveyed, placed and compacted and to the requirements.

D.3.1 Loosening, loading and conveying

Soils and rocks are to be loosened, loaded, conveyed and deposited on the construction site or in interim deposits in such a way that they retain their construction capability. If soil, rock or other materials of various suitability occur during loosening, and if they are to be used differently, they should be loosened separately for further separated processing. When loosening rock or rock-like soil, it is aimed at creating particle sizes that allow immediate use as construction material.

D.3.2 Placing and compacting

D.3.2.1 Execution

At the beginning of compaction work, the Contractor needs to verify the suitability of the selected work procedures with a test field to the prescribed requirements for compaction, etc. in the service specification or according to Table D.6. The work process (type of machinery, layer (level and thickness), number of passes, operation speed, settings of amplitude and frequency, etc.) depends on the building material to be compacted and the compaction degree required.

The largest particle size of the building material to be placed shall not be larger than 2/3 the permissible fill height. The placing and compaction work shall be adapted to the weather conditions.

D.3.2.2 Compacting requirements

ZTV E-StB and ZTV-W provide the following requirements for the compaction (Table D.6):

- degree of compaction D_{Pr} (reference to the standard Proctor test);
- air void content n_a.

The location within the earthwork structure of the requirements of embankments and cuttings (Table D.6) are presented in Figure D.3.

For waterways, these requirements (ZTV-W) will ensure sufficient safety against erosion and suffusion for dams.

Table D.6 — Requirements for the 10 % minimum quantile for degree of compaction D_{Pr} (reference to the standard Proctor test) or for the 10 % maximum quantile for air voids content n_a

No	Location within earthwork structure and function	Soil groups	D_{Pr} [%]	n_a [vd.-%]
1.1	embankments: from formation level to 1,0 m depth cuttings: from formation level to 0,5 m depth	GW, GI, GE SW, SI, SE GU, GT, SU, ST	100	-
1.2	from 1,0 m under formation level to embankment base		98	-
2	from formation level to embankment base and for cuttings to 0,5 m depth	GU*, GT*, SU*, ST* U, T, OU[1)], OT[1)]	97	12[2)]
3.1	Protective earth dams	GW, GI, GE SW, SI, SE GU, GT, SU, ST	95	-
3.2		GU*, GT*, SU*, ST*, U, T, OU, OT		12
4	Mineral seals	GU*, GT*, SU*, ST*, U, T, OU, OT	95	5
5.1	Dams and dikes for waterways	GW, GI, GE SW, SI, SE GU, GT, SU, ST OH, OK	100	-
5.2		GU*, GT*, SU*, ST*, U, T, OU, OT	97	12

1) For soils of groups OU and OT, the requirements only apply if their suitability and placing conditions have been specially investigated and specified in agreement with the client.

2) If the soils are not stabilized or do not undergo qualified improvement, a requirement on the 10 % maximum quantile for air void content of 8 vol.% is recommended for the installation of water susceptible mixed and fine-grained soils. The corresponding requirement is 6 vol. % for installation of rocks of variable hardness. These requirements are to be declared in the service specification.

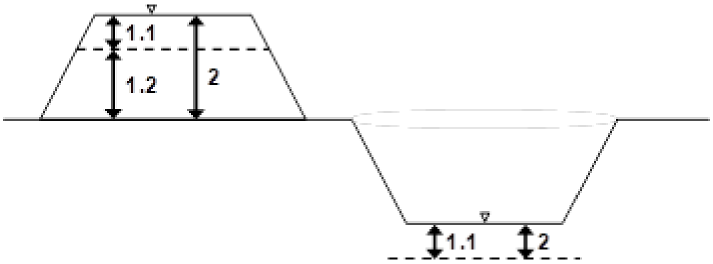
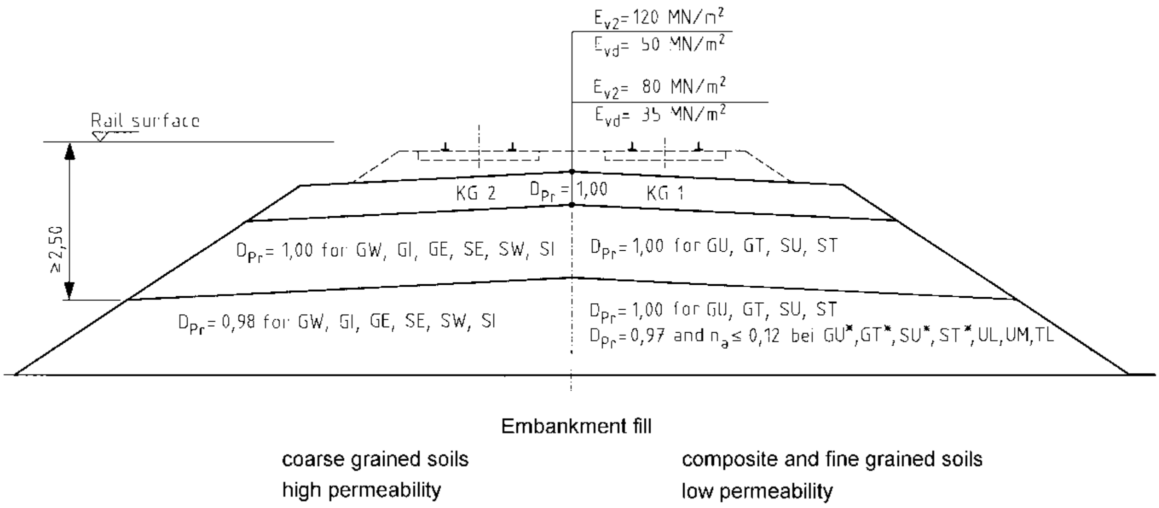


Figure D.3 — Display of location within the earthwork structure (Number see Table D.6)

For building pits and pipe trenches, backfill and covering structures special requirements regarding construction materials and compaction are laid down in ZTV E-StB.

For earthworks structures for railways, the requirements are shown in Figure D.4 (example) according to Ril 836. The requirements differentiate between different types of tracks and different train speeds.



Key

KG1, KG2	special granular soil mixtures for subballast layers
GW	soil Groups according to DIN 18196
D_{Pr}	degree of compaction, ratio to standard Proctor Density
E_{v2}	Deformation Modulus by Static Plate Load Test (d = 30 cm) according to DIN 18134
E_{vd}	Deformation Modulus by Dynamic Plate Load Test (d = 30 cm) according to TP BF-StB, Teil B 8.3

Figure D.4. — Substructure for a railway line with ballasted track and speed up to 230 km/h (Example for use of non treated soils)

D.3.2.3 Modulus of deformation requirements

The requirements to the modulus of deformation on the formation level for roads shown below are with respect to the 10 % minimum quantile.

In the case of a road superstructure on a frost-proof base or substructure (F1 soil) the required deformation modulus on the formation level is adapted to the loading class for the pavement construction (Table D.7).

Table D.7 — Deformation modulus requirements depending on loading classes for pavement construction (according to RStO)

Loading class Bk (RStO)	E_{V2} [MN/m²]	E_{Vd} [MN/m²]
Bk100 to Bk0,8	120	65
Bk0,3	100	50

The modulus of deformation E_{V2} is verified by the static plate load test according to DIN 18134 and the modulus of deformation E_{Vd} by the dynamic plate load test according to TP BF-StB, Part B 8.3.

For a frost susceptible subsoil or substructure (F2 or F3 soil), a modulus of deformation of E_{V2} = 45 MN/m² on the formation level is necessary. After a qualified soil improvement on a frost susceptible base or substructure, a modulus of deformation of E_{V2} = 70 MN/m² on the formation level is necessary.

In ZTV E-StB more earthwork structures, building elements and construction methods, as well as slopes, seals, soakage systems, building pits, pipe trenches and backfills with special requirements are discussed.

For earthwork structures of railways, the requirements for deformation modulus are combined to the requirements of compaction and are shown in D.3.2.2 (Figure D.4).

D.3.3 Special construction methods in earthworks according to ZTV E-StB

D.3.3.1 Soil treatment with binders

Soil treatment includes soil stabilization and soil improvement with binders. Soil treatment is defined by different procedures to treat soils with cement, building lime or combination binders in such a manner so that they reach the required qualities. Criteria for determining the binder quantity in suitability testing depends on the soil group, the kind of building material according TL BuB E-StB and of the kind of binder. The testing procedures are laid down in TP BF-StB, Part B 11.1 and 11.3.

Soil stabilization contains methods which increase the resistance of soil against stress by traffic and climate by the addition of binders, so that the soil becomes permanently stable and frost-resistant. Soil stabilization is carried out in the upper zone of the subgrade (embankment, subsoil or substructure) of roads, as well as in other traffic areas and earthworks. If the subsoil or substructure immediately below the superstructure consists of soil of frost susceptibility class F1, stabilization can be performed with a hydraulic binder. This stabilized soil then becomes part of the superstructure of trafficked surfaces. Characteristic compaction requirements for soil stabilization are defined as follows:

- Using the mixed-in-place technique the layer which will be stabilized shall fulfil the compaction requirements (before stabilization) according to Table D.6.

- The stabilized layer (for mixed-in-place and mixed-in-plant) shall fulfil the compaction requirement of > 98 % DPr of the soil-binder-mixture.

Qualified soil improvement contains methods to improve soils with binders so that those soils fulfil increased requirements for specific characteristics. The requirements for bearing capacity, shearing strength and erosion resistance are increased and the requirements for deformations and frost susceptibility are decreased. The binder quantity shall not exceed 3 wt. %. For qualified soil improvement of the formation level (reduction in frost susceptibility class from F3 to F2), the binder quantity is designed to reach a certain uniaxial compressive strength or CBR value. The requirements of compaction of the respective use in road or earthwork construction shall comply with requirements according to Table D.6.

Soil improvement is a method to improve the handling and the compactibility of soils and to facilitate construction works. This method is used in earthworks in the subsoil, subgrade or embankment of roads and traffic areas. The requirements of compaction of the respective use in road or earthwork construction apply also for soil improvement (Table D.6).

D.3.3.2 Mechanical soil improvement

Mechanical soil improvement can be used in the base of the embankment and in the embankment to improve the handling and the compactibility of soils and to facilitate construction works by intermixing e.g. coarse-grained building materials. For mechanical soil improvement, no binders are used.

D.3.3.3 Geosynthetics

Geosynthetics are geotextiles, geogrids, barriers and composite materials manufactured wholly or predominantly from polymeric materials and which are used in earthworks and drainage systems for road construction.

Geosynthetics shall satisfy the

Technische Lieferbedingungen für Geokunststoffe im Erdbau des Straßenbaus, TL Geok E-StB (Technical terms of delivery for geosynthetics in earthworks for road construction).

Geosynthetics may be used in the following areas for:

- separating two adjacent soil prisms;
- safeguarding slopes against erosion;
- protecting seals against damage;
- reinforcing bodies of earth;
- filtering soils which require drainage;
- draining soils which retain water; and
- sealing against the effects of water or liquids bearing contaminants.

D.4 Control of Earthworks

D.4.1 Types of testing

For quality control testing, three different types of testing are distinguished:

- suitability testing;
- internal control testing (self-monitoring);
- compliance testing.

Suitability testing are tests performed by the Contractor to verify the suitability of the building materials for the intended purpose in compliance with the contractual requirements.

Internal control testing is performed by the Contractor to determine whether the quality of the building materials as well as the executed earthworks meet the contractual requirements. The test results shall be documented in correspondence to the progress of construction.

Compliance testing are tests performed by the client to determine whether the quality of the building materials as well as of the executed earthworks meet the contractual requirements. The acceptance of executed earthworks is based on the results of the compliance tests.

All test results need to be documented throughout the work progress and are part of proof of conformance for acceptance.

D.4.2 Testing methods

The Quality Control is based on three different methods. Each method offers specific advantages depending on its application and type of project. Based on specific conditions of the construction site and the key factors type, size and importance of the earthwork structure, type and composition of the construction material, type and application of machinery, the most suitable method shall be selected. The selected method is part of the technical specification in the contract.

As a matter of principle the Contractor needs to prove the suitability (the contractual requirements for compaction will be fulfilled) of his chosen operating technique (machinery, number of roller passes, working pace, frequency, etc.) on a test field at the beginning of the compaction work.

The main characteristic and requirements which have to be fulfilled are:

- degree of compaction;
- bearing capacity;
- drainage system;
- compaction parameters like dry density, porosity, air void content, longitudinal evenness, transversal profile, deformation modulus.

A distinction is made according to the following methods:

- Method M1 – end product specification according to test plan;
- Method M2 – continuous compaction control;
- Method M3 – method specification and spot tests.

In **Method M1** (TP BF-StB Teil E1) the achieved quality of the end product is determined by random control tests of the relevant parameters like compaction, bearing capacity, water permeability etc. The test results are evaluated based on a statistical analysis whether the requirements are fulfilled (test lot accepted) or not (test lot rejected). Depending on the size of the area which has to be tested the number of required trials is fixed in a table in the standard (ZTV E-StB).

Application of Method M1 is advisable for all types of soil especially for the quality control of large project lots, as well as to verify the uniformity of compaction.

In **Method M2** (TP BF-StB Teil E2) the achieved quality is monitored during the compaction process by rollers. Roller mounted instruments measure a dynamic value determined by the interaction between the roller and the compacted soil which correlates to the stiffness and compaction of each layer. Method M2 requires a calibration of dynamic measurement values against the requirements of compaction for each layer to be built (determination of correlation coefficient). The results of the continuous measurements need to be documented as proof of conformance for acceptance in combination with single compliance testing.

Application of Method M2 is advisable for projects with a high daily output, for projects where compaction assessment is an integral part of the working process and to assess the uniformity of compaction.

In **Method M3** (TP BF-StB Teil E3) the quality control is based on method specification. At the beginning of the compaction work, a trial compaction is executed to verify the suitability of the compaction process to meet the contractual requirements. Based on the results of the trial compaction specific work instructions and work procedures are defined. Key characteristics describing the compaction procedure for the work instructions are for example type of machinery, mass, frequency of vibration, roller passes, soil group, thickness of fill, water content of the fill.

The compaction work shall be executed according to those instructions and procedures. The conformance to these instructions and procedures shall be documented accurately by the contractor in the course of self-monitoring the work progress. This documentation (daily log) serves as proof of conformance (quality control) for acceptance in combination. Additionally a defined number of compliance testing (spot test) shall be conducted.

Application of Method M3 is advisable for projects with minor importance and on sites with uniform soil types and uniform environmental and operation conditions.

D.5 References

DIN[1)]

DIN 4020 *Geotechnical investigations for civil engineering purposes*

DIN 4094-4 *Subsoil - Field testing - Part 4: Field vane test*

DIN 18121 *Soil, investigation and testing – Water content*

DIN 18122-1 *Soil, investigation and testing - Consistency limits - Part 1: Determination of liquid limit and plastic limit*

DIN 18122-2 *Soil, investigation and testing - Part 2: Determination of the shrinkage limit*

DIN 18123 *Soil, investigation and testing - Determination of grain-size distribution*

DIN 18125 *Soil, investigation and testing – Determination of density of soil*

DIN 18126 *Soil, investigation and testing - Determination of density of non-cohesive soils for maximum and minimum compactness*

DIN 18127 *Soil, investigation and testing – Proctor test*

DIN 18128 *Soil, investigation and testing - Determination of ignition loss*

DIN 18136 *Soil, investigation and testing - Unconfined compression test*

DIN 18137-2 *Soil, investigation and testing - Determination of shear strength - Part 2: Triaxial test*

DIN 18196 *Earthworks and foundations – Soil classification for civil engineering purposes*

DIN 18299 *German construction contract procedures (VOB) – Part C: General technical specifications in construction contracts (ATV) – General rules applying to all types of construction work*

DIN 18300 *German construction contract procedures (VOB) – Part C: General technical specifications in construction contracts (ATV) – Earthworks*

FGSV[2)]

Additional technical conditions of contract and directives for earthworks in road construction (ZTV E-StB 09), FGSV 599 E

Technische Prüfvorschriften für Boden und Fels im Straßenbau, Teil E1 Prüfung auf statistischer Grundlage – Stichprobenprüfplane, TP BF-StB Teil E1, FGSV 591

Technische Prüfvorschriften für Boden und Fels im Straßenbau, Teil E2 Flächendeckende dynamische Prüfung der Verdichtung, TP BF-StB Teil E2, FGSV 591

Technische Prüfvorschriften für Boden und Fels im Straßenbau, Teil E3 Prüfung der Verdichtung durch Probeverdichtung und Arbeitsanweisung, TP BF-StB Teil E3, FGSV 591

Technische Prüfvorschriften für Boden und Fels, Teil E4 Kalibrierung eines indirekten Prüfmerkmals mit einem direkten Prüfmerkmal, TP BF-StB Teil E4, FGSV 591

Technische Lieferbedingungen für Geokunststoffe im Erdbau des Straßenbaus, TL Geok E-StB, FGSV 549

Merkblatt über die Verdichtung des Untergrundes und Unterbaus im Straßenbau, FGSV 516

Merkblatt über flächendeckende dynamische Verfahren zur Prüfung der Verdichtung im Erdbau, FGSV 547

Merkblatt über Bodenverfestigungen und Bodenverbesserungen mit Bindemitteln, FGSV 551

Merkblatt über die Behandlung von Böden und Baustoffen mit Bindemitteln zur Reduzierung der Eluierbarkeit von umweltrelevanten Inhaltstoffen, FGSV 560

Merkblatt zur Herstellung, Wirkungsweise und Anwendung von Mischbindemitteln, FGSV 564

Technische Prüfvorschriften für Boden und Fels im Straßenbau, Teil B11.1, Eignungsprüfung von Bodenverfestigungen mit hydraulischen Bindemitteln TP BF-StB Teil B11.1, FGSV 591

Technische Prüfvorschriften für Boden und Fels im Straßenbau, Teil B11.3, Eignungsprüfung für Bodenverbesserungen mit Bindemitteln TP BF-StB Teil B11.3, FGSV 591

DGGT[3)]

DGGT-Recommendation No. 1 'Unconfined compressive strength at cylindric rock test bodies' of the AK 3.3 'test-technology Rock'

Others

Ril 836 Erdbauwerke und sonstige geotechnische Bauwerke planen, bauen und instandhalten, DB Netz AG [4)]

Zusätzliche Technische Vertragsbedingungen – Wasserbau (ZTV-W) – für Wasserbauwerke aus Beton und Stahlbeton (Leistungsbereich 215)

Reference Source

[1)]Beuth-Verlag GmbH

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[3)]DGGT Deutsche Gesellschaft für Geotechnik e. V.

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Annex E
(informative)

Summary of national practice - Norway

E.1 Introduction

There are several standards, specifications and handbooks describing earthworks in Norway.

The most commonly used are:

Norwegian standard NS 3458 *Compaction - Requirements and execution*

This standard gives general requirements for compaction of mass for roads, squares, fills etc.

Norwegian standard NS 3420-F *Specification texts for building, construction and installations - Part F: Earthworks - Part 1*

Handbooks from the Norwegian Public Roads Administration (NPRA):

Handbook N200; *"Road Construction"*

Handbook V221; *"Ground improvement, fills and cuts"*

Handbook R761; "*General Specifications 1 Standard specification for road contracts" (Prosesskode 1)*

Jernbaneverkets tekniske regelverk: Underbygning – Prosjektering og bygging

E.2 Classification of materials

Recommended practices concerning the classification of materials include:

- organization of site investigations in successive phases (guide);
  - planning and execution of site investigations and trial tests in successive phases as basis for geotechnical design (stability, bearing capacity);
  - assessment of suitability as fill material and excavation;
- identification of families of material with similar behaviour (description of GTR classification for soils and rocks, with synthetic table);
- typical fill material to be considered:
  - good quality or blasted or crushed rock;
  - granular fill;
  - moraine;
  - weathered or stiff clay with low water content;
- description of by-products and alternative materials, including environmental assessment (guide).

Alternative materials are:

- light expanded clay aggregates;
- foamed glass;
- EPS (expanded polystyrene);
- crushed concrete;

— first outline of earth movement, analysis of available volume of each material family, evaluation of their possible uses and eventual extraction problems (guide). Typically, soft sensitive clays (quick clay) and silts are unsuitable as construction fills under normal conditions, without extensive treatment.

E.3 Design of earthworks

E.3.1 Dredging

Execution of dredging can be done by use of different kinds of equipment. Dredging procedures are divided into two main groups: suction dredging and mechanical dredging. These two main groups are again split, depending of the equipment:

Suction:

- plain suction dredger (SD);
- cutter suction dredger (CSD);
- trailing suction hopper dredger (TSHD).

Mechanical:

- backhoe dredger (BHD);
- grab dredger;
- bucket dredger.

In Scandinavia and especially Norway, the topography is such, that suction dredging is not used much. Suction is preferred for dredging of contaminated material if other selection criteria suit this type of dredging. Grab dredging and backhoe dredging is the preferred dredging equipment in Norway. The reason for this is that most of dredging projects in harbor and fairways include dredging of hard soil, like moraine, boulder clay, etc. and also removal of blasted rock.

Therefore the most important item for the selection of dredging equipment is “Soil conditions”. The dredging equipment has to be able of dredging the soil expected in the deepening area.

In national standards (NS 3420), there is a limitation of when digging the soil, without any kind of loosening, cannot be expected (25 MPa). Loosening of hard moraine can be done with ripping and use of special kind of grabs.

E.3.2 Underwater blasting

In Norway most of the rock is hard, for example granite. Then drilling and blasting is very common in deepening projects in Norway.

Equipment for drilling can be floating barges and jackup rigs. Barges can be used in protected areas. Barges have operating limits for waves and also have other restrictions based on the kind of mooring. If the drill barges are moored by anchor, it is important that anchor lines do not to create any obstacle for other traffic.

Jackup rig are preferred because they can operate more or less unobstructed by waves, and have no kind of anchor lines.

Execution of blasting shall be done in accordance with national and local restrictions. All use of explosives is restricted by national laws, for buying, transport and storage.

Local and project restrictions can be like shock restrictions, noise restrictions and pressure load to existing constructions. It is also important to clarify distance to fish farms. All these aspects shall be considered in planning of the blasting work. Also different types of mitigation techniques shall be described. Example of such technique is bubble curtain for reducing shock waves.

E.3.3 Transportation at sea

Transport of different kinds of material can be performed using different kinds of equipment. It can be flat top barges or hopper barges. Hopper barges can be split barges, self-propelled or towed barges.

Criteria for the type of barges to be used include:

- type of masses;
- disposal sites;
- depth;
- transport distance.

Split barges are preferred where material has to be dumped at deep water disposals. That gives a fast and effective discharging of materials. For transportation of boulders, flat top barges can be suitable.

E.3.4 Spreading and compaction of fills

E.3.4.1 Introduction

Specifications for compaction of fills are given in the Norwegian Standard NS 3458, *"Compaction – Requirements and execution"* and in the Norwegian Public Roads Administration (NPRA) Handbook N200; *"Road Construction"*. In addition, NPRA has published guidelines to Handbook N200, Handbook V221; *"Ground improvement, fills and cuts",* which is the most commonly used guideline for execution of earthworks in Norway.

NS 3458 is the most commonly used specification on projects where documentation on achieved compaction is not considered absolute crucial (execution specifications rather than achieved result), see *Normal* and *Light Compaction* below. The same goes for rock fill and course grained material not suitable for Proctor tests. On the other hand, where achieved compaction and documentation is considered crucial, the NPRA specifications and guidelines are commonly used. This is based on Proctor values and testing for fill material suitable for this testing. For rock fills and course grained materials, test fills with levelling and, if available, CCC registrations after each pass of the compaction equipment is used to decide layer thickness and number of passes.

E.3.4.2 Norwegian Standard NS 3458 "Compaction – Requirements and execution"

This standard defines maximum layer thickness and number of passes depending on material type, compaction equipment and degree of compaction needed ("Normal", "Light" or "Special").

This clause gives an overview of the most relevant parts of the standard related to general earthworks (fills and embankments).

Mass type

Different material types covered by the standard are defined and broken down into 7 groups (A-G), depending on material type and particle size according to Table E.1.

Table E.1 — Material groups

Group	Material type	Comments
A	Blasted rock	Unsorted blasted rock
B	Crushed aggregate	E.g. crushed rock, coarse crushed rock and recycled concrete
C	Gravel	Non-water sensitive material (max. 7 % fines)
D	Sand	Non-water sensitive material (max. 7 % fines)
E	Fine sand and silt	Use shall be specially assessed
F	Clay	Dry crust clay or firm plastic clay. Use shall be specially assessed
G	Lightweight aggregate	E.g. aggregate of recycled glass, lightweight clay and lightweight crushed concrete

Compaction class

There are three different classes of compaction; light, normal and special.

Which compaction class to use shall be decided for each case according to professional geotechnical assessment, based on requirements for stability, load-bearing capacity, maximum acceptable settlement and side-support for pipes and structures.

Compaction work is expressed through number of passes by the compaction equipment and the maximum layer thickness prior to compaction, depending on the material to be compacted.

Normal Compaction and Light Compaction will in most cases give a compaction degree of 95 %–100 % Standard Proctor and 90 %–95 % Standard Proctor respectively.

Compaction class "Special Compaction" shall be used if special compaction procedures or documentation is required. In this case special design, specifications and requirements for execution, testing and accept criteria shall be given.

Compaction specifications given in Table E.2 apply to general earthworks. For natural material, the requirements are restricted to materials with uniformity coefficient: $C_U \geq 5$. For even-graded material in group C, D and E, special specification of compaction is required.

This table does not give any requirements for the layer thickness and number of passes for clay. Compaction of clay shall be specified separately.

Requirements for layer thickness and number of passes for considerably heavier compaction equipment than stated in Table E.2 should be given special assessment.

Maximum stone size is two thirds of the layer thickness.

Table E.2 — Requirements for normal and light compaction of fill (earthworks)

Group Material type		Compaction equipment		Maximum layer thickness prior to compaction (m)	Number of passes for class[c]	
		Type	Mass[a] in kg, static linear load[b] in kN/m or ground pressure in kPa		Normal	Light
A Blasted rock		Vibrating roller	26 – 40 kN/m	1,00	8	4
			41 – 55 kN/m	1,50	8	4
			> 55 kN/m	2,00	8	4
B Crushed aggregates (crushed stone, coarse crushed rock, concrete)		Mechanical tamper[d]	60 - 70 kg	0,30	4	2
		Vibrating plate	50 – 100 kg	0,20	6	4
			101 – 200 kg	0,30	6	4
			201 – 500 kg	0,40	6	4
			> 500 kg	0,50	6	4
		Vibrating roller	10 – 15 kN/m	0,30	6	4
			16 – 25 kN/m	0,50	6	4
			26 – 40 kN/m	0,60	6	4
			41 – 55 kN/m	0,70	6	4
			> 55 kN/m	0,80	6	4
C, D Gravel or sand		Mechanical tamper[d]	60 - 70 kg	0,30	4	2
		Vibrating plate	50 – 100 kg	0,15	6	4
			101 - 200 kg	0,20	6	4
			201 - 500 kg	0,30	6	4
			> 500 kg	0,40	6	4
		Vibrating roller	10 – 15 kN/m	0,30	6	4
			16 – 25 kN/m	0,40	6	4
			26 – 40 kN/m	0,50	6	4
			41 – 55 kN/m	0,60	6	4
			> 55 kN/m	0,70	6	4
E[e] Fine sand or silt		Mechanical tamper[d]	60 - 70 kg	0,30	4	2
		Vibrating plate	50 - 100 kg	0,15	6	3
			101 - 200 kg	0,15	6	3
			201 - 500 kg	0,20	6	3
			> 500 kg	0,30	6	3
		Vibrating roller	10 – 15 kN/m	0,20	5	3
			16 – 25 kN/m	0,30	5	3
			26 – 40 kN/m	0,40	5	3
			> 40 kN/m	0,60	5	3
F[f] Clay		-	-	-	-	-
G Light-weight aggre-gate	Lightweight clay, lightweight crushed concrete	Tracked machinery	≤ 50 kPa	1,00	2	2
		Vibrating plate[g]	50 – 200 kg	0,60	2	2
	Aggregate of recycled glass[h]	Tracked machinery	≤ 50 kPa	1,00	2	2
		Vibrating plate	50 - 200 kg	0,60	2	2

[a] For tampers, plates and wheeled machines
[b] Value applies to the vibrating unit for vibrating machines
[c] Tandem roller gives two passes per run
[d] Impact machinery can have other designations
[e] Fine sand and silt are water-sensitive masses and can therefore be unsuitable
[f] Clay fills are described in accordance with special compaction
[g] Not suitable for even-graded lightweight clay
[h] If aggregate of recycled glass is used as lightweight fill under roads/airfields (as part of the sub-base), compaction shall only be performed with tracked machinery. If there is no access for tracked machinery, use vibrating plate.

Guideline values for water content in the fill material to achieve good results for *Normal* and *Light Compaction* are given for Material group A – G in Table E.3.

Table E.3 — Recommended values of water content for Normal and Light compaction

Group	Material type	Water content
A	Blasted rock	
B	Crushed aggregates, all-in aggregates with $d = 0$	4–10 %
	Coarse crushed rock and crushed rock	
	Crushed concrete	
C	Gravel	4–8 %
D	Sand	6–12 %
E	Fine sand, silt	6–14 %
F	Dry crust clay or firm plastic clay.	Up to 30 %
G	Lightweight masses	

Rock fill

The Norwegian practise summarized here is based on the NPRA specifications and guidelines.

Rock-fill materials for embankments will normally be obtained from road cuts in rock, tunnelling operations or from borrow pits. Blasted rock from open pits will normally have a favourable rock size distribution and is therefore preferable. It is desirable that the amount of fines is as small as possible.

Rock type and blasting methods are vital factors.

Normally the rock quality will be satisfactory, but some rock types are not suitable. This applies to rock with a high degree of foliation, weathered rock and rock with high mica content. A combined evaluation of degree of foliation, weathering and mica content should be performed in relation to embankment height, slope inclination, internal fill stability, permeability and deformations in order to decide if the rock-fill material is suitable as embankment material.

If the rock-fill material is open, no requirements are applied regarding amount of fines, but if the particle sizes are uniformly graded, maximum 8 % of the material should be less than 0,063 mm and the humus content should not exceed 3 % ignition loss measured on material less than 0,5 mm.

Rock from tunnelling operations may, when the blasting operations are adjusted, provide suitable rock-fill material. Often, however, rock from tunnelling operations produces high amounts of fines which may have to be removed.

Materials from TMBs (Tunnel Boring Machine) are heavily crushed and may have a particle size distribution similar to sand/gravel and should be used accordingly.

Materials favourable for embankments are rock with relatively large and uniform sizes having cubical shapes and without appreciable amounts of fines.

Examples of good quality rock material are granite, gabbro and gneiss. Examples of poor quality rock material are phyllite, micaschist and other strongly weathered and flaky rock types.

E.3.4.3 Construction procedures for rock-fill

E.3.4.3.1 Road embankment height < 6 m:

Road embankments and other fills with high quality requirements shall be performed according to the procedures described for embankments with height > 6 m.

For embankments with less restricted requirements regarding fill deformations, the embankment may be placed by tipping from a level 1 m below the formation level.

If the ground slope has an inclination of 1:3 or steeper in the transverse direction of the road, the rock-fill material should be placed and compacted in layers. The fill material should consist of untreated blasted rock with the largest stone size less than two-thirds of the fill height or layer thickness and with the largest side edge ≤ 1,5 m. Less size stones (e.g. 0,5 m) will contribute to reduce separation during spreading. The fill material should be tipped on the existing fill and then pushed over the edge by a bulldozer or similar equipment. Embankment slopes should be monitored continuously in order to ensure even slopes with expected inclination. If steeper slopes arise, the slope inclination shall be adjusted.

At a level 1 m below the formation level compaction shall be performed. Compaction shall be carried out with vibrating rollers according to guidelines in Table E.4.

Table E.4 — Selection of vibrating roller for rock embankment

Fill material	Compaction equipment	Static linear load [kN/m]	Layer thickness after compaction [mm]	Number of passes
Blasted rock	Vibrating roller	> 45 > 30	Placed on end-tip 500–2000	10 5

The remaining part of the embankment is placed in one layer and compacted according to Table E.4.

E.3.4.3.2 Road embankment height > 6 m

When the embankment height is > 6 m, the rock-fill material should be placed in layers of thickness 1-3 m. Each layer is compacted. The rock-fill material may consist of blasted rock with the largest rock size less than two-thirds of the layer thickness and with the largest side edge ≤ 1,5 m.

Compaction shall be performed with vibrating roller according to requirements given in Table E.4.

E.3.4.4 Deformations

Embankments placed by tipping and compacted as described, is expected to exhibit deformations of the order of up to 1 % of the total embankment height. Deformations may be expected to continue for at least 6 months after construction, but may be accelerated during heavy rainfall or due to flushing with water during construction.

Construction during winter time when there is frost in the air may lead to less compaction effects and may result in larger fill deformations. Deformations will also continue for a longer period than when the embankment is placed in non-freezing conditions.

Embankments being placed in up to 3 m thick layers with compaction of each layer may exhibit deformations in the order of 0,5 % of the embankment height. The major part of these deformations is expected to be concluded 6 months after construction. The deformations may be further reduced by reducing the layer thickness and increase compaction efforts.

E.3.4.5 Construction procedures for granular soils

Norwegian practise on spreading and compaction of granular soils (sand and gravel) is based on the same principles as in most other countries with spreading and compaction in layers of 0,2-0,6 m thickness. Specifications are either given by equipment/layer thickness/number of passes or by Standard Proctor.

Normally a maximum content of fines should be 8 % and the organic content should be less than 3 %.

E.3.4.6 Construction procedures for clay fill

Clay fills of high quality in Norway are mainly built as road embankments. The practice described here is based on specifications and guidelines from the Norwegian Public Roads Administration (NPRA).

Design and construction of clay fills requires substantial expertise regarding soil behaviour, geotechnical design principles and practical execution of earthworks.

Material requirements

Most of the clay material used in embankments can be described as dry crust material. Soil investigations include soil sampling and laboratory tests. Assessment of material quality is mainly based on grain size distribution (Figure E.1), water content and shear strength:

Clay content:	10 - 40 %
Water content:	15 - 30 %
Undisturbed shear strength:	> 50 kPa
Remoulded shear strength:	> 10 kPa

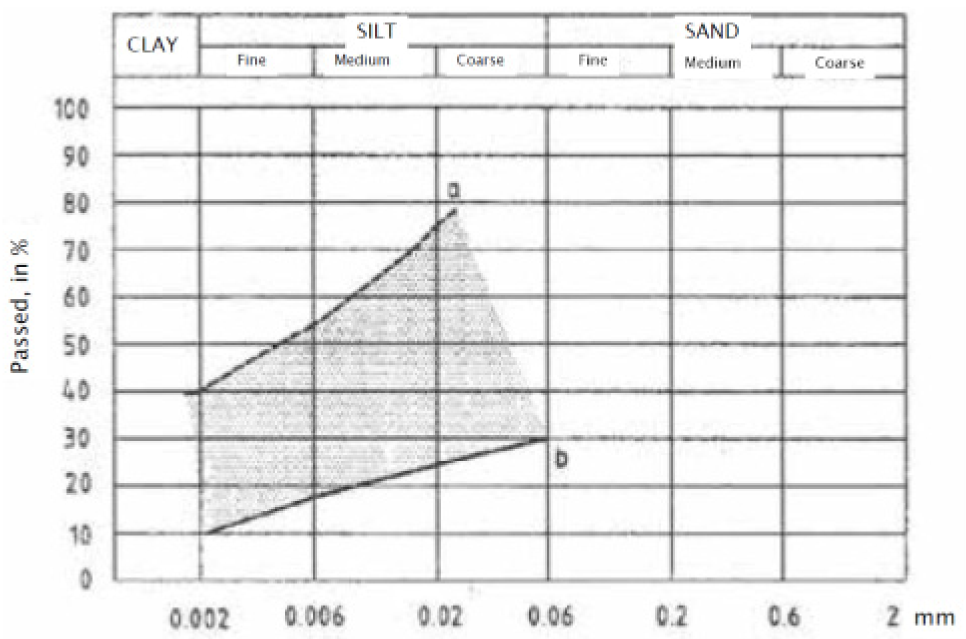


Figure E.1 — Experience-based grain size distribution range for Norwegian clay fills

Construction procedures

Stability and settlement issues shall be addressed as part of the design. Counterfills (Lateral berms) are a normal part of the design for high clay embankments. Benching and removal of soft topsoil are part of the preparation for the basis as for other types of fills. Attention shall be paid to the measures for water drainage from the ground under the fill, if necessary.

The work with clay fills is restricted with respect to the influence of rain and frost, and is therefore performed during the summer season.

The clay is normally placed in the fill with layer thickness 200 mm after compaction. A 200 mm sand layer is placed in the fill at 1,4 m intervals, and the sand layers are connected with sand columns as shown in Figure E.2.

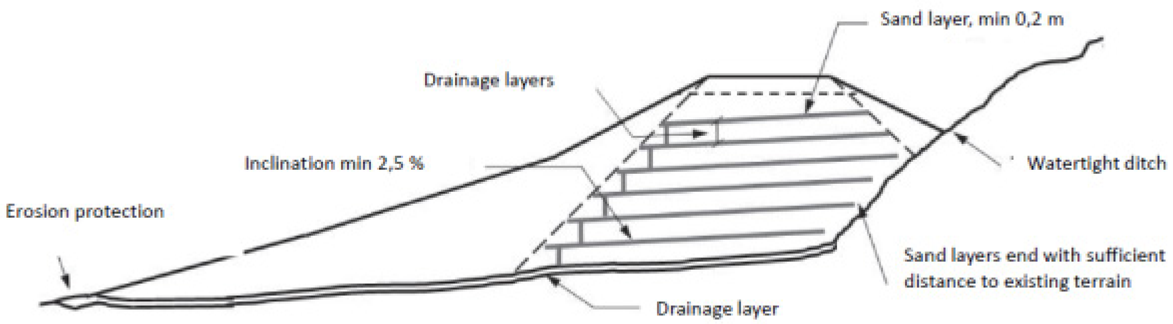


Figure E.2 — Clay embankment with internal drainage

The clay layers are normally placed with a dozer. Compaction of each layer is performed with dozers or wheel machines (e.g. dumper trucks), depending on the water content and stiffness of the fill material (see Table E.5).

Table E.5 — Recommendations for compaction equipment

Material	Compaction equipment	Weight (t)	Layer thickness after compaction (mm)	Number of passes
Clay, silty clay (upper part of moisture range)	Dozer, LGP	10–20	200	2–4
Clay, silty clay (lower part of moisture range)	Wheel machine (dumper truck, etc.)	15 - > 30	200	2–4

An example showing the work pattern during compaction is given in Figure E.3.

Figure E.3 — Work pattern during compaction

A compaction requirement based on achieved wet density is given in Figure E.4.

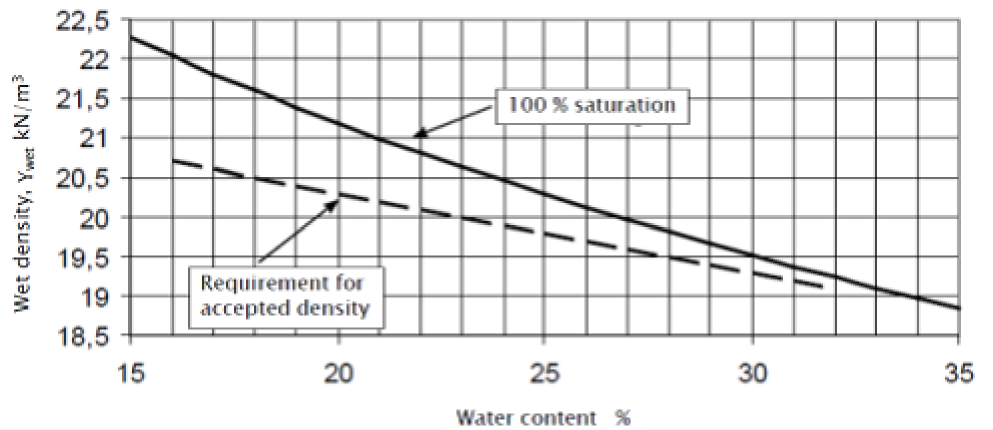


Figure E.4 — Example of compaction requirement for clay fill

More detailed specifications for clay fills are given in the NPRA guideline V221.

E.3.5 Filling under water

E.3.5.1 General

Special care shall be taken to provide safety at sites with soft soil deposits, either by removal, replacement, displacement, improvement of the soft soil or by other stabilizing measures.

Special information on site conditions, in addition to soil conditions, relevant for planning under water filling are:

- geometry of the site, including boundary conditions;
- topography;
- access;
- slopes and headroom restrictions;
- water depth and seabed slope and topography;
- existing underground structures, pipes and cables, services, known contaminants and archaeological constraints;
- environmental restrictions including noise, vibration, displacements, pollution and effects of seasonal variations in weather including frozen surface layers;
- meteorology and environmental data such as waves, current and tides.

E.3.5.2 Execution

There are special considerations when filling under water.

Filling under water can be performed by:

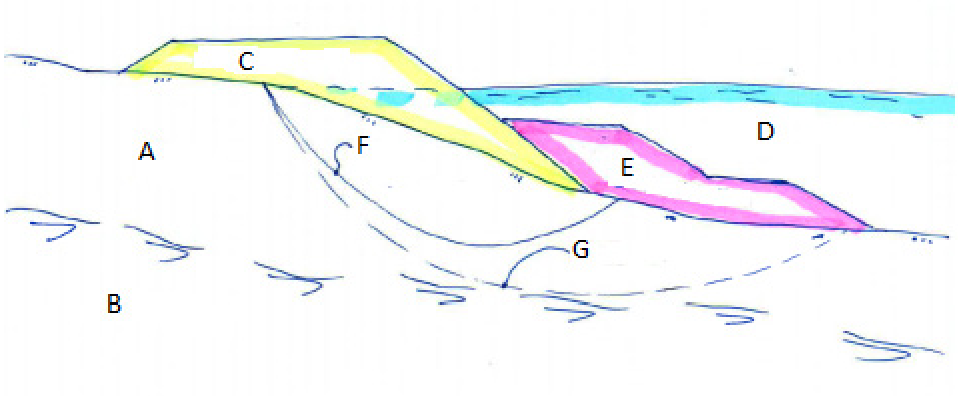
- dumping from above the water level;

For safety reasons, the fill material is dumped at least 5 m away from the fill edge and pushed out with a dozer or placed with an excavator;

- dumping from a barge.

Filling from a barge might be necessary from a safety perspective (stability, building the fill from the deepest water and up towards dry land) or from a fill quality perspective (more homogeneous fill).

If a counterfill (buttress) shall be established simultaneously with the main filling (Figure E.5), the level difference between the counterfill and the main fill shall, for stability reasons, not at any time be higher than the final designed level difference. Filling is performed in accordance with given layer thicknesses, etc.



Key

A soil
B bedrock
C embankment
D water
E counterfill
F failure without counterfill
G stable with counterfill

Figure E.5 — Typical cross-section of a fill raised in water

The embankment is placed up to a level just above the water line. Compaction shall then normally be performed, for example by using a vibrating roller with line load 30–45 kN/m and with 6–10 passes. For further fill above water, normal procedures for compacted fill are used.

If special deformation requirements are given, the fill may be compacted by dynamic deep compaction or by temporary surcharge.

Erosion and wave protection shall be placed according to the design.

E.3.5.3 Fill materials

For embankments under water, coarse granular material and rockfill is commonly regarded as suitable. If placed behind a rockfill jetty or coffer dam, other materials as silt, sand and gravel can also be used for filling under water.

Rock-fill materials for embankments will normally be obtained from road/railway cuts in rock, tunnelling operations or from borrow pits. Blasted rock from open pits will normally have a favourable rock size distribution and is therefore preferable. Rock type and blasting methods are vital factors.

Normally the rock quality will be satisfactory, but some rock types are not suitable (weathered rock and water susceptible material). Examples of poor quality rock material are phyllite, micaschist and other strongly weathered and flaky rock types.

Normally the maximum rock size should be limited to approximately 1 m. If steel piles are to be driven through the embankment, the largest rock size may not exceed 0,5 m.

Rock from tunnelling operations may, when the blasting operations are adjusted, provide suitable rock-fill material also for embankments in water.

Materials from TBMs (Tunnel Boring Machine) are heavily crushed and may have a particle size distribution similar to sand/gravel. This material may be used for landfills but is unsuitable for embankments in water unless it is placed behind a rock fill jetty or cofferdam.

The expansion factor from solid rock to blasted rock-fill material may according to experience be taken as:

- embankment above water: 1,35 –1,45;
- embankment in water: 1,50 –1,55.

For embankments in water, it is important to be aware of that larger volume than the theoretical volume calculated from cross section profiles will be required, maybe up to 20 % more. The reason is that a fair amount of materials ends up outside the embankment profile due to inaccurate filling procedures or strong currents, deformations in the fill and displaced subsoil material.

E.3.5.4 Embankment slopes

Embankment slopes shall be considered in the design and during construction.

Natural inclinations of slopes for rockfill in water are listed in Table E.6. Steeper slopes are not considered to provide satisfactory stability.

Calculated safety margins for surface stability according to geotechnical design standards may require that the slope is inclined at a lesser angle.

Slopes subjected to external forces, environmental forces (currents, waves, ice drifts etc.) may also require less inclination or other countermeasures. Embankments constructed with blasted rock of poor quality and/or flaky form (shale) and unfavourable rock size distribution (high amount of fines) or due to filling from tip, may result in appreciably less steep side slopes.

Table E.6 — Indication of steepest, advisable embankment slopes under-water depending on rock quality and production method

Rock from	Steepest advisable side slope below water	
	Good rock quality and cubical rock	Poor rock quality and flaky rock
Open pit blasting	1:1,3	1:1,5 to 1:2
Tunnel blasting	1:1,3 to 1:1,5	1:1,5 to 1:1,6
Tunnel boring machine	not applicable	not applicable

In order to avoid sliding in the front area of the fill and for the safety of workers on the fill, the inclination of embankment slopes shall be monitored. Steep slopes shall be detected and the inclination reduced.

Observation of slope inclinations may be carried out by normal profiling methods (sounding) or by use of acoustic echo sounder.

Embankment slope adjustments can be obtained by excavator or by performing blasting where overhang or too steep a slope is observed.

The need for blasting operations should be evaluated and detailed plans prepared.

E.3.6 Replacement / displacement of soft soil

When specified in the design, the replacement or displacement of soft soil shall be assessed.

Soft subsoil replacement can be performed by excavation at the foot of the fill during the filling process to ensure that the fill material penetrates down to stable (firm) soil. Soft subsoil displacement can be performed by blasting and requires special design and execution procedures. Special work procedures are required for both methods to ensure safe conditions for the filling operation.

E.3.7 Influence of weather conditions

The influence of weather and seasonal temperature changes shall be taken into account in the design and planning of earthworks.

Frozen soil, snow and ice are not allowed in fills, unless it is designed as a deposit.

E.4 Quality control of earthworks

The Norwegian practise of quality control summarized here is based on NPRA Norwegian Public Roads Administration Handbook N200: "Road Construction".

In addition NRA NPRA has published guidelines to Handbook N200, Handbook V221; "Ground improvement, fills and cuts", which is the most commonly used guideline for execution of earthworks in Norway. The quality control is also based on The Norwegian Standard NS 3458; "Compaction – Requirements and execution".

Quality control of compaction for road fills shall be executed according to Table E.7.

Table E.7 — (to be translated)

(Foreslår at vi oversetter og setter inn følgende tabell fra N 200 og V221):

Kontroll av	Kvalitetskrav til	Kontrollomfang			
		Pr. mengde-enhet	Minimum antall prøver		Dokumenta-sjon
			H, S	A	
Utsprengt berg					
- Klassifisering	Materialtype [1]	Hvert lag	V	V	Loggbok [5]
- Komprimering	Antall passeringer, krav optimaliseres ut fra setnings-nivellement (Figur 256.3, kap. 520.133)	Hvert lag	V	V	Loggbok [5]
Friksjonsmasser Grovkornige					
- Klassifisering	Jordartsbestemmelse [2]	Hvert lag	V	V	Loggbok [5]
	[6]	10 000 m^3	1[2]	1[2]	Analyseresultat
- Komprimering	Antall passeringer (Figur 256.3)	Hvert lag	V	V	Loggbok [5]
Friksjonsmasser Selvdrenerende					
- Klassifisering	Jordartsbestemmelse [2]	Hvert lag	V	V	Loggbok [5]
	[6]	10 000 m^3	1[2]	1[2]	Analyseresultat
- Komprimering	Ved oppstart: Densitet (Figur 203.3)	Ved start	1	1	Analyseresultat
	Ved drift: Antall passeringer	Hvert lag	V	V	Loggbok [5]
Silt, leire og leirig morene					
- Klassifisering	Jordartsbestemmelse [3] [6]	2000 m^3	1	V	Analyseresultat
- Komprimering	Densitet	Hvert lag	1[4]	1[4]	Måleresultat
	Lagtykkelse 20 cm	Hvert lag	1	1	Måleresultat

H = Hovedveg S = Samleveg A = Adkomstveg
V Visuell kontroll (hvert lag pr. 150 m fyllingslengde)

1) For berg: Blokkstørrelse, petrografi (visse bergarter)
2) For friksjonsmasser: Korngradering, humusinnhold og vanninnhold: Minst en prøve pr. fylling og for hver 10 000 m^3
3) For silt/leire: Vanninnhold, plastisitet og korngradering: Minst en prøve pr. fylling og for hver 2000 m^3, ved fet leire kan prøveomfanget reduseres.
4) 5 doble avlesninger med isotopmåler (Troxler)
5) Loggbok skal inneholde følgende: Dato utført arbeid evt. Klokkeslett, sted, lag nr., lagtykkelse, materialtype, utført komprimeringsarbeid, evt. prøvetaking, signatur av utførende/kontrollerende og merknadsfelt
6) Angitt volum gjelder pam3 (prosjektert anbrakte masser)

Figur 2-0- 20 Kontrollomfang for fyllinger

Requirements for degree of compaction (Standard Proctor) are given in Table E.8.

Table E.8 — (to be translated)

Plassering i fylling	Dimensjoner-ende krav SP	Densitetsmålinger 5 prøver eller flere		Densitets-målinger Mindre enn 5 prøver SP
		Middelverdi SP	Enkeltverdi SP	Enkeltverdi SP
0–3 m under traubunn	97 %	Min. 98 %	Min. 93 %	Min. 96 %
Dypere enn 3 m under traubunn	95 %	Min. 96 %	Min. 91 %	Min. 94 %

Figur 2-0- 21 Krav til densitet for friksjonsmasser i fylling (andel av Standard Proctor SP)

In situ density testing for quality control (nuclear density testing, sand replacement, liquid replacement) shall be performed according to Handbook 015 Field testing.

E.5 References

NPRA Handbook N200 (2014) Road construction (in Norwegian):
http://www.vegvesen.no/_attachment/188382/binary/980128?fast_title=H%C3%A5ndbok+N200+Vegbygging+%2821+MB%29.pdf

NPRA Handbook V221 (2014) Ground improvement, fills and cuts (In Norwegian)):
http://www.vegvesen.no/_attachment/61506/binary/964921?fast_title=H%C3%A5ndbok+V221+Grunnforsterkning%2C+fyllinger+og+skr%C3%A5ninger+%2814+MB%29.pdf

Annex F
(informative)

Summary of national practice - Spain

F.1 Introduction

Basis of rock and soil mechanics and earthworks are supposed to be well known for professionals. Generally, description of materials in field is made on geological basis and identification of materials is done according to the USCS system and ISO EN 14688 or ISO EN 14689.

The most commonly used specification for earthworks in Spain is *Pliego de Prescripciones Técnicas Generales para Obras de Carreteras y Puentes (PG-3)* regulation (Clauses 322 and 330 to 333) from Dirección General de Carreteras (State Road Administration). Projects for specific construction sites may introduce additional specifications or requirements.

It can also be other specifications for different uses or clients, but when existing, they are very often referred to PG-3.

PG-3 includes soil and rock classification for earthworks purpose, basics of earth-structure design criteria (generally it does not include aspects covered by EN 1997-1), construction procedures, quality control and -as a regulation, being a part in public contracts- criteria for payment. When field or laboratory tests are required, they are referred to European standards EN or, if they are not available, to national standards UNE.

The first printed version of PG-3 dates from 1976 (it existed previously with different status); it was updated in 2000 to 2002 according to official procedure for technical regulations by European Commission (Directive 98/34/EC).

The following summary is about PG-3, Clauses 330 to 333.

F.2 Classification of materials

F.2.1 General

In addition to natural soils and rocks, products from industrial processes or human manipulation may be used in earth or rock fills, provided their compliance with the specifications of PG-3. In any case, they shall meet the following requirements:

— provisions of the legislation about the environment, health and safety, and storage and transport of construction products shall be observed;

— physical and chemical properties of materials shall be able to guarantee both, short and long-term stability and service conditions of the earth-structure.

Spanish national practice in earthworks is based in classification of materials to be used in fills; their origin could generally be a quarry, pit or any cut or excavation built *in situ* for the new infrastructure. It comprises five classes of material obtained from soils and two main classes of material obtained from rocks.

F.2.2 Soil classes

Soil classes, ordered by decreasing acceptance, to be used in earthfills, are as follows:

— Selected (Seleccionado)

— Suitable (Adecuado)

— Acceptable (Tolerable)

— Marginal (Marginal)

— Unacceptable (Inadecuado)

Soils are put into one of these five classes depending on several simultaneous conditions referred to properties obtained from laboratory tests. To be included into one class, a soil shall comply with all the listed conditions; thus a soil is classified according to its worst assessment for any of the properties included in Table F.1.

Table F.1 — Classification criteria for soils

	Selected soil	**Suitable soil**	**Acceptable soil**	**Marginal soil**	**Unacceptable soil**
Content in organic matter	< 0,2 %	< 1 %	< 2 %	< 5 %	
Content in soluble salts	< 0,2 %	< 0,2 %	Gypsum < 5 % Other < 1 %	No limit	
Free swelling in oedometer	no swelling	no swelling	< 3 %	< 5 %	
Collapse settlement in oedometer	no settling	no settling	< 1 %	No limit	
Maximum size	< 100 mm	< 100 mm	-	-	
Sieved through #2mm sieve	< 80 %	< 80 %	-	-	
Sieved through #0,40mm sieve	< 75 %	No limit	-	-	
Sieved through #0,08mm sieve	< 25 %	< 35 %	-	-	
Plasticity (w_L, I_P)	See in Plasticity Chart" (Figure F.1.)	See in Plasticity Chart (Figure F.1.)	See in Plasticity Chart (Figure F.1.)	See in Plasticity Chart (Figure F.1.)	See in Plasticity Chart (Figure F.1.)

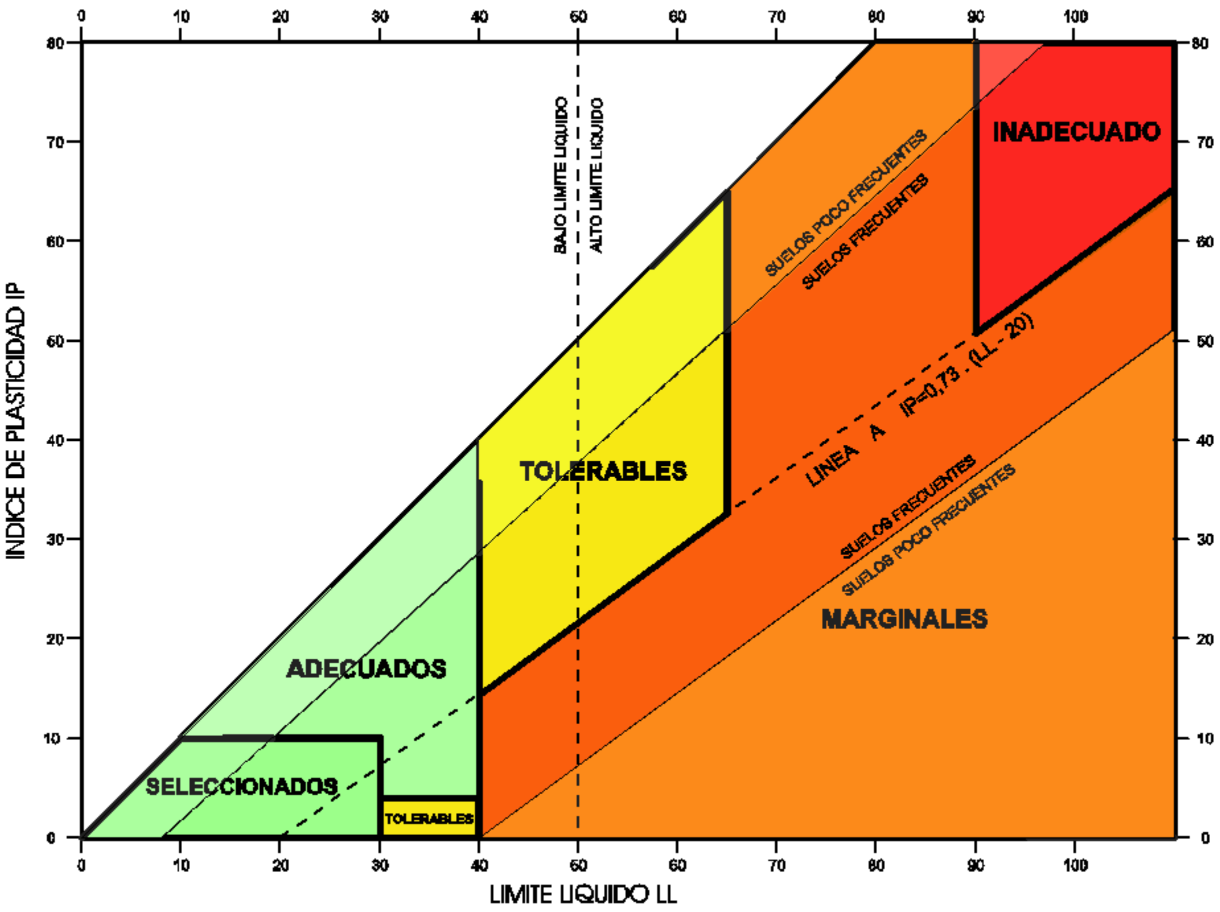


Figure F.1 — Plasticity chart

As an example, a soil sample with the following properties: #0,08 mm = 34 %, #2 mm = 78 %, organic matter = 0,1 %, no soluble salts (gypsum included), no collapsible, free swelling in oedometer = 4 %, is considered to be marginal. Thus a special study needs to be developed to analyse the possibility of its use in the core of the cross section, and to define special prescriptions which should be performed during construction.

F.2.3 Fill classes built with rocky materials

There are two classes of fills built with materials obtained from rocks depending on the grain size distribution obtained in the excavation/placement procedure and on the stability of the particles when submerged in water:

- rock fill (#220 mm < 50 %; #55 mm < 25 %; #14 mm < 12,5 %; stable particles when submerged in water);
- random fill, rest of cases. The classification of random fill follows the same criteria as the classification of soils (with fraction of particle size under #20 mm).

Rock and random fill is accepted for all parts of the cross section of earth-structure except the upper zones, in which transition zones shall be designed.

F.3 Possible use of marginal materials

It is possible to use marginal materials after a specific study for each construction site. PG-3 gives some basic recommendations to develop such studies for different types of marginal materials, some of them being common all over the country.

When this specific study determines that they can be used, they shall only be used in the core of the cross section, taking into account all prescriptions defined by the study.

F.3.1 Some marginal soils

F.3.1.1 Soils sensitive to collapse

A soil is sensitive to collapse when it settles more than 1 % at the collapse test, performed in an oedometer under standard Proctor conditions for the sample. Collapse phenomena may occur in gypsiferous silts, some other silty formations and soils with carbonate cement. Compaction should be a bit wetter than optimum, and modified Proctor as reference should be required.

F.3.1.2 Soils sensitive to swelling

A soil is sensitive to swelling when it swells more than 3 % at the free swell test, performed in an oedometer under standard Proctor conditions for the sample. It may be used only in the core providing a specific study, if it swells less than 5 %. Compaction should be a bit wetter than optimum, and standard Proctor as reference should be required.

F.3.1.3 Soils containing gypsum

Gypsum ($CaSO_4\ 2H_2O$; solubility in water = 2,40 g/l at t = 20 °C) is a particular case of soluble salt, common all over the country. Its content shall be determined by means of laboratory tests. Depending of its content, it may be used in different areas of the cross section of earth-structure:

— less than 0,2 %: any place;

— between 0,2 % and 2 %: in the core;

— between 2 % and 5 %: in the core, but special care is required when choosing materials for shoulders and upper layers;

— between 5 % and 20 %: in the core, with special disposition of impermeable and drainage layers or special facilities to make sure that no water reaches the core (e.g: impervious sheets, double pipes - one inside other- for transverse drainage);

— more than 20 %: As above, but only if there is no other available material.

F.3.1.4 Soils containing soluble salts different to gypsum

The salt content shall be determined by means of laboratory tests. Depending on its proportion in the soil, identification of mineral species could be needed (as solubility ranges various magnitude orders) then special tests are required: X-ray diffraction or other studies. Depending of the salt content, the conditions of use are as follows:

— less than 0,2 %: the soil can be used for any salt and any area on the cross section of earth-structure;

— between 0,2 and 1 %: it can only be used in the core of the cross section of earth-structure;

— more than 1 %: a specific study is required, identification of mineral species is always needed.

F.3.1.5 Soils containing organic matter

Organic matter content is determined by a $KMnO_4$ based test. The rules are as follows:

— in earth fills of up to five metres high (≤5 m), soils containing less than five per cent organic matter (OMC < 5 %) may be allowed in the core, provided that the expected deformation has been taken into account by the designer;

— in earth fills of more than five metres height (>5 m), the use of soil containing more than two per cent of organic matter (OMC > 2 %) shall be justified by a specific study;

— in the upper zone, the content in organic matter shall always be less than one per cent (OMC < 1 %).

F.3.2 Some marginal rocks

F.3.2.1 General

If the fraction passing through the # 20 mm sieve is qualified as a marginal soil, then the rock is classified as a marginal rock and a specific study is required in order to use it, taking into account the percentage of fines, exposition to external agents and the characteristics of its location within the core of the cross section of the fill.

When this specific study determines that they can be used, they can only be placed in the core of the cross section, taking into account all prescriptions defined by the study.

Some types or rocks are also defined as marginal ones, and need a specific study for use in the core of rock or random fill:

F.3.2.2 Evolutive rocks

When subjected to a degradability test (under national standard), the sample cracks or disintegrates or losses more than two per cent (2 %) in weight.

F.3.2.3 Rock containing oxidizable sulphides

Rocks which are found to contain pyrites or other oxidizable sulphides. Their degradation may attack concrete.

F.3.2.4 Rock containing soluble minerals

Similar figures and prescriptions than in the case of soluble soils.

F.3.2.5 Rock containing combustible minerals

When the content in organic matter is more than two per cent (OMC > 2 %). This topic essentially involves waste from coal.

F.3.2.6 Shape marginality

The content of particles with an unsuitable form has to be less than 30 per cent (<30 %). To this end, particles in which the following inequality is confirmed, are regarded as having an unsuitable form: $(L+G)/2 \geq 3E$:

— L (length) = maximum distance between two parallel planes tangent to the particle;

— G (width) = diameter of the minimum circular hole through which the particle passes;

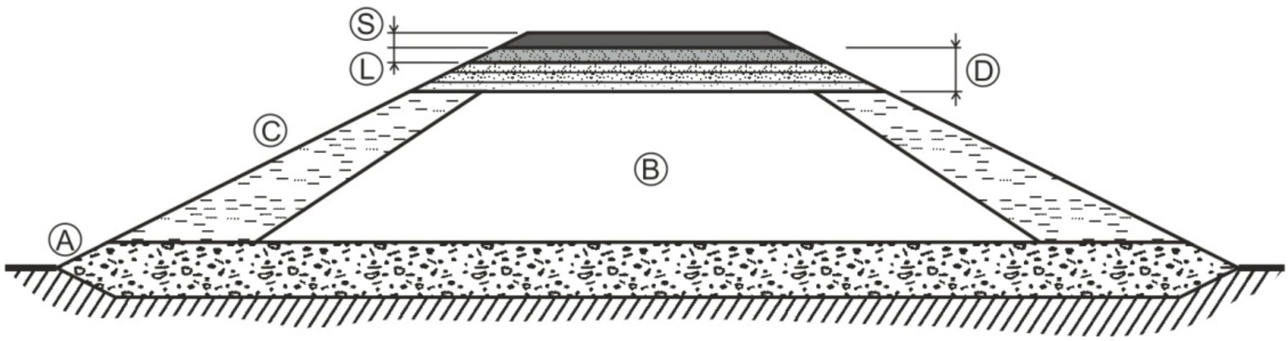
— E (thickness) = minimum distance between two parallel planes tangent to the particle.

These values do not necessarily have to be measured in three orthogonal directions.

F.4 Preliminary design of earth-structure cross section

At any earth-structure, different zones can be defined in a cross section. Materials to be placed on them, and final requirements shall also be different.

Definition of zones of infrastructure embankment (Figure F.2) coincides with 6.2.2 in this European Standard. Low embankments may not allow the formation of all the zones defined for the general case. Drainage design completes the whole definition of the cross section.



Key

A base;

B core;

C shoulders;

D upper zone;

L capping layer (part of upper zone);

S superstructure (Pavement)

Figure F.2 — Zones of infrastructure embankment: general case

A) Base

This is the lower part of the earth fill in contact with the supporting area. It shall be at least one metre thick (1 m).

Acceptable, suitable or selected soils shall be used. CBR index corresponding to the compacting conditions for use shall be greater than three ($I_{CBR} \geq 3$).

B) Core

This is the part of the earth-structure between the foundation and the upper zone.

Acceptable, suitable or selected soil shall be used. CBR index corresponding to the compacting conditions for use shall be greater than three ($I_{CBR} \geq 3$).

The use of marginal soils or those with a CBR index less than three ($I_{CBR} < 3$) may be possible, but dependent on strength, deformability and usage issues; in all cases, it shall be justified by a specific study for each construction site. In case the specific study allows its use, this is the only place in cross section where marginal materials can be used.

C) Shoulders

This is the outer part of earth-structure. It may include planting, topsoil cover, paving, anti-erosion protection, etc.

Acceptable, suitable or selected soils shall be used which fulfil the design conditions regarding imperviousness, strength, weight and erosion protection. Expansive or collapsible soil may not be used in this area.

When the core is formed with expansive or collapsible soils, or material containing soluble salts or sulphates greater than 2 % (in terms of weigh) the shoulders shall prevent infiltration of water into the core.

D) Upper zone

This is the upper part of the earth-structure, which may include capping layers and supports the superstructure. Its minimum thickness shall be the larger value among: thickness of two layers or 50 cm (50 cm).

Suitable or selected soil shall be used. CBR index corresponding to the compacting conditions for use, shall be in any case greater than five ($I_{CBR} \geq 5$) or the value provided by the design as the minimum required for the type of subgrade supported.

Others

Also specific zones may be defined between core and upper zones or capping layers, also between special sections (riprap protection in river basins, reinforced fill areas, etc.) and the rest of the fill, to provide adequate particle size transitions if needed.

F.5Types of earthstructures to be built

Four types of earth-structures are defined:

— earthfill (Clause 330);

— rockfill (Clause 331);

— random fill (Clause 333);

These three types of fill depend on the raw material (soils or rocks, and their particle size conditions), but they will all be built by using heavy machinery.

A fourth type of fills is defined for small volumes, areas near pipes or structures, or for any specific cause defined in the design, when light compaction processes need to be used:

— localized fills (Clause 332).

F.6Basic construction rules

F.6.1 Preparation of the ground area to build the earth or rockfill

For most cases, earth or rockfill is to be constructed on natural ground, this area shall first be cleared, drained and let to the shape and elevations prescribed in the design. The layer of vegetal topsoil has to be removed, and generally stocked, except in cases that the design specifications may dispense the removal of topsoil (for fills more than 10 m in height, where the deferred settling is minor and provided that its presence does not pose any risk of instability).

Ground or soil treatments, substitutions, improvement, or building of earth-structures supported by pre-existing ones, is not considered in this summary of current national practice.

Where indicated in the design, layers of coarse granular material or geotextile sheets shall be spread to allow or facilitate the application of the first layers of fill (base).

F.6.2 Earthfills

F.6.2.1 Spreading of the layers for earthfills

Once the ground area has been prepared, the fill will be constructed using the materials defined above which shall be spread in successive layers of uniform thickness and essentially parallel to the final subgrade.

Layer thickness shall be adequate to obtain the required compaction degree, in general 30 cm for earthfills, but always more than 3/2 of the maximum size of the material.

The spreading shall be planned and carried out so that the materials in each layer are uniform; if not, uniformity shall be achieved by mixing materials using appropriate machinery. No layer may be spread until it has been checked that the underlying surface complies with the required conditions.

The surface of the layers has to be able to drain rainwater by means of a transverse gradient, generally around four per cent (4 %).

Unless otherwise specified the earth transport and spreading equipment shall operate across the whole width of each layer and, in general, along the line (axis) of the road.

F.6.2.2 Wetting or drying a layer

If it is necessary to add water to achieve the specified degree of compaction, this operation shall be carried out by uniformly wetting the materials in the source areas (quarries, borrow pits), in intermediate stores or very often in the layer just before compaction, with suitable systems being used to ensure this uniformity (commonly sprayed by tank wagons).

In special cases where the natural moisture of the material is excessive, appropriate measures shall be taken to achieve the specified compaction, with the possible use of drying by airing to sun or the addition and mixing of dry materials or appropriate substances.

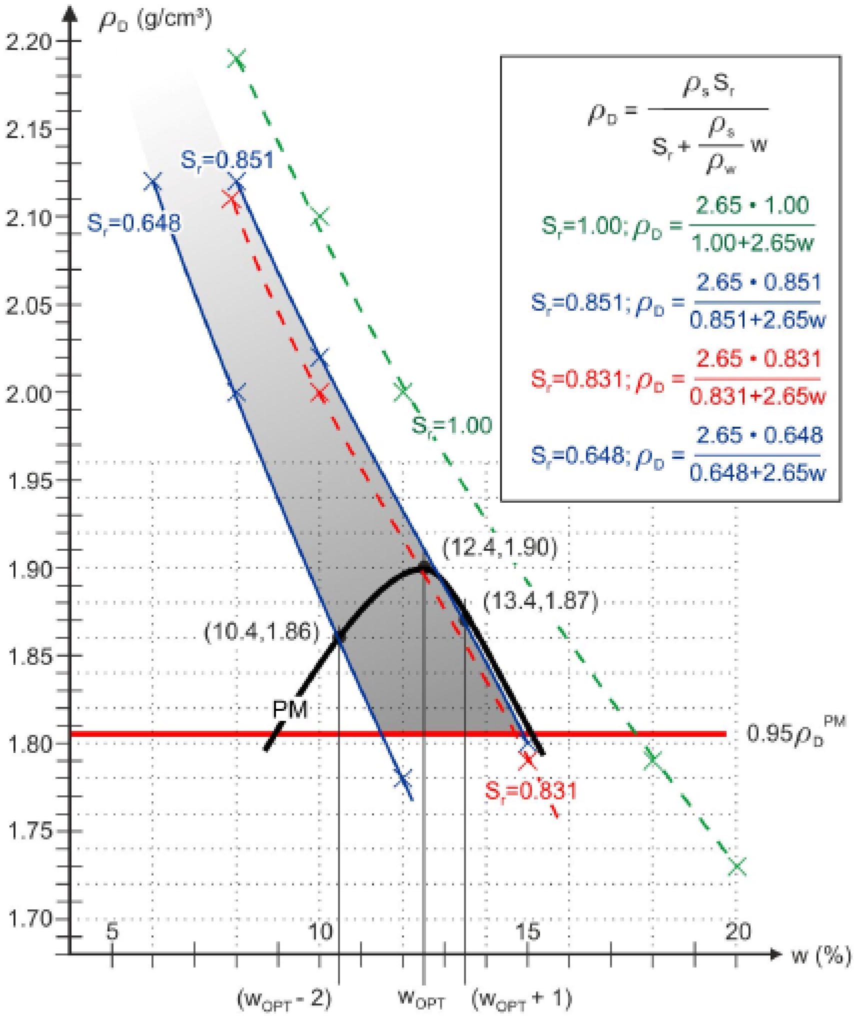
F.6.2.3 Compacting

Once the most appropriate wetting (or exceptionally drying) has been achieved, the mechanical compacting of the layer can begin.

The density and moisture values to be achieved are those defined in the design, according to following rules (which can be taken as a particularisation of those contained as general ones in 6.3.4 of this document):

— For a given material, the compaction degree is fixed with respect to the maximum reference Proctor dry density. To choose the reference Proctor there are two possibilities, Standard or Modified test (the later with higher specific energy, but less water content required in the optimum). Unless a different criterion is specified, reference Proctor shall be the Modified test, except for compaction of expansive soils (then Standard test). Compaction degree required is 100 % in the upper zones and a value equal or higher than 95 % in all others (defined for every specific case).

— Water content required is that which produces a saturation ratio between the one at the reference Proctor optimum plus and minus a margin S_r ($w = w_{OPR} - 2$ %) to S_r ($w = w_{OPR} + 1$ %). An example is given in Figure F.3. If the soil is sensitive to collapse or swelling, the margins are slightly different: S_r ($w = w_{OPR}$ - 1 %) to S_r ($w = w_{OPR}$ + 3 %).



$$\rho_D = \frac{\rho_s S_r}{S_r + \frac{\rho_s}{\rho_w} w}$$

$$S_r = 1.00;\ \rho_D = \frac{2.65 \cdot 1.00}{1.00 + 2.65w}$$

$$S_r = 0.851;\ \rho_D = \frac{2.65 \cdot 0.851}{0.851 + 2.65w}$$

$$S_r = 0.831;\ \rho_D = \frac{2.65 \cdot 0.831}{0.831 + 2.65w}$$

$$S_r = 0.648;\ \rho_D = \frac{2.65 \cdot 0.648}{0.648 + 2.65w}$$

Figure F.3 — Example of determination of validity zones in an earth-fill (given as reference Modified Proctor curve of the soil; required minimum dry density for this specific case = 0,95ρ_D^{PM})

The spreading and compacting of a new (upper) layer requires the acceptance of the previous one below it. Until it has not been accepted, works for a new layer should not start.

F.6.3 Rock and random fills

F.6.3.1 Spreading of the layers

Once the supporting base for the fill has been prepared, the fill is constructed using the rocky materials spread in successive layers of uniform thickness and essentially parallel to the subgrade.

The material for each layer shall be unloaded on site onto the part of each layer already spread and near to its front edge. From this position, it will be pushed to the front of the layer and then spread from this by a tractor equipped with a shovel. In special cases the rock fill may be sprayed with water.

The general thickness for random fills will be 40 to 60 cm, and in all cases more than 3/2 of the maximum size of the material. If layers are thicker than 40 cm (40 cm), control of compaction shall be performed in order to look for values at bottom of a layer.

For rockfills, the general layer thickness will be 60 to 135 cm and in all cases, more than 3/2 of the maximum size of the material.

F.6.3.2 Compacting

The approved procedure shall guarantee that the minimum compaction required is obtained. To this end, the grain-size distribution of the material, the thickness of the layers, the type of compacting machinery and the number of passes of the equipment shall be chosen according to each area of the rock fill. These variables will be determined from the results obtained during the adjustment of the working method.

If vibrating rollers are used, the dead weight of the equipment may not be less than 10 tonnes (10 t). For fills from friable rock, the compaction may be increased with an initial crushing of the material using a suitable “goatsfoot” roller in the early passes.

F.6.3.3 Adjustment of the working method

The approval of the specific working method will depend on its on-site testing. This testing consists in the construction of an experimental fill of a volume no less than three thousand cubic metres (3 000 m^3), with the aim of checking the suitability of the proposed method, or adapting it:

— random fills: at least three (3) layers with a minimum width of 8 m;

— rock fills: at least two (2) layers with a minimum width of 10 m.

More details are given in F.7.

F.7 Control of earthworks

F.7.1 General

Tolerances, frequencies for calibration and auxiliary procedures are also defined in PG-3.

F.7.2 Earthfills

F.7.2.1 Tests to be performed

At the production place (quarries, pits, or cuts) soil materials shall be classified in uniform lots (3 Proctor tests / 20 000 m^3, with maximum variation of 3 % for moisture content and 2 % for dry density). For each lot, mean values of reference Proctor test will be used for control of construction.

For construction (once specific validity zones are defined for each lot, taking into account the specific material which is going to be used), PG-3 mainly applies an end product specification (see 12.2 of this document) in which the “product” is each layer built; once a layer is approved, the next one can be spread over it. In each layer it will be checked that:

— dry density is greater than the minimum specified and saturation degree is between the fixed (upper and lower) limits defining the *validity zone* (see F.6, and example in Figure F.3);

— stiffness is checked mainly using a static load plate test:

  — minimum value of E_{V2}:

    — Base, shoulders or core: Selected soils EV2 ≥ 50 MPa, other types of soil EV2 ≥ 30 MPa;

    — Upper zone: Selected soils EV2 ≥ 100 MPa, other types of soil EV2 ≥ 60 MPa;

  — ratio $E_{V2}/E_{v1} \leq 2{,}2$.

Other compaction control methods or tests may also be used (footprint, geophysical tests, dynamic plates or others, with target values not specified), but they need to be checked at different times with the previous one.

In addition, some topographical registers and checks of the procedure (e.g. thickness and transverse slope of layers) are done.

F.7.2.2 Frequencies of testing

A portion for control is defined as the smallest area resulting from the following criteria applied to a single earth fill layer:

— length of 500 m;

— area of 3 500 m^2 in upper zones and 5 000 m^2 in all other areas (some differences for small embankments);

— work done in a day;

— work done using the same material, borrow pit, equipment and compacting procedure.

Every portion shall be tested for:

— dry density + moisture content: 5 random points (central) + 1 point/100m of edge;

— stiffness: 1 test.

F.7.3 Rock and Random fills

F.7.3.1 General

PG-3 applies mainly a method specification (see 12.3 of this document), with differences between random and rockfills.

F.7.3.2 Random fills

During the construction of the experimental random fill (see F.6), the grain-size distribution of the recently excavated and of the spread material, and the moisture and dry density of the compacted material shall be determined, generally by digging a test pit (area S > 1 m^2, volume V > 1 m^3).

The surface deformation of the random fill and the mean density of the compacted material will be determined using topographical procedures, after each pass of the compacting equipment.

A minimum of four (4) passes is required and the settlement produced by the last pass shall be less than one per cent (1 %) of the thickness of the layer to be compacted.

Once the ***construction method*** has been approved, it shall be checked that it is always followed. Some control tests are also performed (or allowed): footprint, same as in earthfills (when possible) or geophysical tests.

F.7.3.3 Rock fills

During the construction of the experimental rock fill (see F.6), the size distribution of the recently excavated and of the spread material, and the density of the compacted material shall be determined by digging a test pit (any dimension > 5 D_{max}, area S > 4 m^2, volume V > 4 m^3).

The surface deformation of the random fill and the mean density of the compacted material shall be determined using topographical procedures, after each pass of the compacting equipment.

A minimum of four (4) passes is required and the settlement produced by the last pass shall be less than one per cent (1 %) of the thickness of the layer to be compacted; also final porosity will be $n < 30$ %.

Once the ***construction method*** has been approved, it shall be checked that it is always followed. Some control tests are also performed (or allowed): footprint or geophysical tests.

In both, rock and random fills, there is a strict topographical control.

F.8Reference

Pliego de Prescripciones Técnicas Generales para Obras de Carreteras y Puentes (PG-3) regulation (see Clauses 322 and 330 to 333), from *Dirección General de Carreteras* (State Road Administration).

Reference in European Commission (Technical Regulations Information System, TRIS) database as: 2000/695/E.

Link to the document (Languages: English, French, German, Spanish):

http://ec.europa.eu/enterprise/tris/en/search/?trisaction=search.detail&year=2000&num=695

Annex G
(informative)

Summary of national practice – Sweden

G.1 Introduction

Sweden generally applies Eurocode 7 and its related documents.

G.2 Classification of materials

G.2.1 Introduction

Soils are classified with respect to grain size distribution. The identification and classification is done according to EN ISO 14688-1 and EN ISO 14688-2. Identification and classification of rock is done according to EN ISO 14689-1.

If the soil contains large boulders (>630 mm) it should be indicated if the content is expected to exceed 1 %.

If the particle size distribution, particle shape, etc. indicate that the soil is a moraine (till) that should always be stated. The soil should in such cases be classified as “Moraine”.

Sweden has a classification system for excavation of soils. However, this is obsolete and nowadays rarely used.

Natural materials used in earthworks are divided into material classes. For manufactured and recycled materials, a special investigation should be conducted which describes the material properties. In some cases, a petrographic study should be conducted to determine the material class for rock.

G.2.2 Soil classification

The material is classified primarily with respect to content of fines, clay content and organic content. The following classes of materials are used for soils:

- coarse-grained soils, including boulder soil and stoney soils, Class 2;
- medium-grained soils, Class 3A and 3B;
- fine-grained soils (clay), Class 4 A and 4B;
- fine-grained soils (silt), Class 5A;
- soils with organic content of 2 - 6 %, Class 5B;
- organic soils (organic content more 7 – 20 %), Class 6A;
- organic soils (organic content more than 20 %), Class 6B;
- manufactured and recycled materials and similar, Class 7.

If the soil, with respect to its genesis, is moraine, this should always be specified.

Organic soils like peat should be classified according to von Post test (scale H1 - H10).

This classification is used in the empirical/mechanistic design system for the pavement layers for roads.

A special classification is given for frost heave potential, which is used in the design of thickness of the pavement layers. The connection between frost heave potential and material classes can be seen in Table G.1.

Table G.1 — Frost heave potential and material classes

Frost heave potential	Description	Material class
1	Material which not heave	Class 2 and 6B
2	Some heave	3A and 3B
3	Medium heave	4A and 4B
4	Large heave	5A and 5B
1 - 4	Variable	6A

The Swedish system for classification is illustrated by Table G.2, from the geotechnical requirements for roads and railways (TK Geo, Table 5.1-1, available on the homepage of the The Swedish Transport Administration, www.trafikverket.se).

Table G.2 — Classification of rock and soil in material classes

Material class for soil	Material class for rock	Nordic ball mill value	Fines* 0,063/63 mm	Clay* 0,002/ 0,063 mm	Organic content* % / 63 mm	Examples (according to ISO identification)	Material class for frost heave potential
1	1 2	≤ 18 19–30	< 10		≤ 2		1
2			≤ 15		≤ 2	Bo, Co, Gr, Sa, saGr, grSa, GrMn, SaMn	1
3A	3	> 30	≤ 30		≤ 2		2
3B			16–30		≤ 2	siSa, siGr, Mn	2
4A			31–40		≤ 2	clMn	3
4B			> 40	> 40	≤ 2	Cl, ClMn,	3
5A			> 40	≤ 40	≤ 2	Si, clSi, siCl, SiMn	4
5B					3–6	gyCl, gySi	4
6A					7–20	clGy, siDy	3
6B					> 20	Pt, Gy	1
7	Other materials according to separate investigation					Manufactured and recycled materials	
*The content of (weight %) x/y.							

The system described is used both as a basis for design of structures, design of earthworks and for other earthworks applications.

G.2.3 Rock classification

The material class is determined by the Nordic ball mill value (A_N) for crushed material. A_N has a correlation with the Micro Deval value. The following classification is used for rock materials:

- rock class 1 (A_N max 18);
- rock class 2 (A_N 18 - 30);
- rock class 3 (A_N larger than 30).

G.3 Design of earthworks

The total settlement of the embankment, including the foundation soil, is calculated regarding differential settlements longitudinal and perpendicular to ensure that the allowed values should not be exceeded.

Slope stability is checked to ensure sufficient stability regarding undrained and drained conditions. In case of weak layers in embankment or foundation soil, these layers shall be included in the analysis.

Material in the surface layer, both in the cutting and on the embankment, have to be selected and checked because the design of the pavement depends on the material mainly for frost heave design but also for design of bearing capacity.

Maximum grain size of material down to 4 m below the road surface shall not exceed two-thirds of the layer thickness.

For wet material from classes 3, 4 and 5 with water content above optimum, the material is compacted to a low air-void. Wet material in the embankment then shall consolidate for 3-9 month before the pavement is constructed.

The time for consolidation can be reduced if drainage layer are installed in the construction. Vertical distance between the drainage layers shall comply with the designed consolidation time, with a recommended maximum vertical distance of 2,0 m. The drainage layers should consist of sand, with a minimum thickness of 200 mm. The gradient (slope) should be at least 2,5 %.

Pavement layers in Sweden often include a frost protection layer of sand or crushed rock with a thickness between 0,1 and 1,5 m.

Road construction shall be drained at least 0,3 m below the formation level.

G.4 Control of earthworks

Normally, method specification requirements are used for earthworks. End product requirements (stiffness, E_{V2}) are usually used on the surface of the formation level.

For road and railway projects, the largest layer thickness after compaction and minimum number of passes for specified compaction equipment are required in a method Specification. The requirements are different depending on the actual material class.

An example of method requirements is presented in Table G.3.

Table G.3 — Requirements for compaction (example)

Equipment	Material class 1 and 3A	Material class 2	Material class 3B and 5B	Material class 4	Minimum number of passes
Vibrating single drum roller min 15 kN/m	Not applicable	0,30 m	0,25 m	0,20 m	6
Vibrating single drum roller min 30 kN/m	1,0 m	0,55 m	0,40 m	0,30 m	6
Vibrating single drum roller min 45 kN/m	1,5 m	0,80 m	0,55 m	0,40 m	6
Vibrating single drum roller min 60 kN/m	2,0 m	1,00 m	0,70 m	0,50 m	6

Requirements are given in this manner for different type of compaction equipment.

Stiffness requirements on the formation level depend on the type of structure and the distance from road surface.

The stiffness of the top layer of the fill or the cut, which is the basement for the pavement layers, is checked. The most common method of testing stiffness is performed with a static plate load test. The E_{v2} value should be minimum 20 to 40 MPa for a flexible pavement depending on the pavement design.

The E_{v2} values given above are mean values of normally 8 checkpoints in a control area of maximum 5000 m^2. If continuous compaction control (CCC) by roller is used, the checkpoints can be reduced to only 2, performed in weak areas.

Annex H
(informative)

Summary of national practice - United Kingdom

H.1 Introduction

This informative Annex briefly summarizes the standards that cover the field of earthworks in the United Kingdom. The UK practice satisfies the requirements of the set of TC396 standards.

The British Standard that covers the field of earthworks is BS 6031:2009 Code of practice for earthworks [3], it reflects the widespread UK practice of using the Specification for Highway Works (SHW) 600 series for the construction of earthworks [1]. This Annex to TC396 prEN 16907-1 has been prepared as a brief summary of these documents to enable engineers who are not familiar with the UK earthworks system to consider utilizing it on projects where appropriate.

The prEN 16907 series has been developed to address the elements of an earthworks project in terms of the following overall phases of activity:

a) selection of materials: fill material identification and classification (prEN 16907-2);

b) design: process to determine how to utilize the fill materials available, including the preparation of the earthworks project Specification (prEN 16907-1), and determination of the appropriate methods of earthworks construction to meet the Specification criteria (prEN 16907-3); and

c) QA/QC testing to control the works (prEN 16907-5).

The UK system has been developed since 1945 specifically to address the task of earthworks construction. The three phases (a) to c)) listed above are all covered within that system, with the phases being inter-linked and inter-dependent. Therefore, it is not appropriate for an earthworks project to use one element of the UK system in isolation; for example, the classification system (a)) is developed specifically to suit the design based approach required (b)). This informative Annex summarizes the phases of design input required by the UK system for earthworks, and how these satisfy the requirements of prEN 16907-1 to -5.

BS 6031:2009 is the UK's national code of practice for earthworks. It is an all-encompassing code of practice; the document has been developed to enable it to cover all earthworks projects, with the exception of dams. BS 6031:2009 is aligned with Eurocode BS EN 1997-1:2004 and its supporting family of documents. As a code of practice, BS 6031 is not a normative standard and takes the form of guidance and recommendations, which should not be quoted as if it were a specification. However, there is an expectation that any project will address its requirements.

H.2 Classification of materials

BS 6031:2009, 3.1 defines the basic principles and terminology to be used for identification and classification of soils for use as earthworks fill materials. Clause 5 of the BS provides guidance on issues to be considered during the planning stage of an earthworks project, and Clause 6 sets out the requirements for site assessment and investigation, including the description and classification of soils and rocks (which is in accordance with the EN ISO 14688 series and EN ISO 14689, respectively), and details the requirements for classification of earthworks fill materials (following excavation), which is in accordance with Tables 6/1 and 6/2 of the SHW (extracts are provided for illustration at Clause H.3.8 of this annex).

The SHW standard classification system for earthworks materials includes various classes of fill material as presented in Table H.1. These classes fall into nine main groups of fill materials that have different intended end uses. These groups can be summarized as follows:

- “General fill” is used for the construction of bulk earthworks (i.e. the main body of an embankment) and these can comprise Class 1 “granular fill” (with less than 15 % fines), Class 2 “cohesive fill” or Class 3 “chalk fill”;
- Class 4 “Landscape fill” is material that can be used to construct landscape areas; the classification is set broadly to permit the use of as wide a range of materials as possible;
- Class 5 “Topsoil” is sub-divided depending on whether it is site won or imported;
- Class 6 “Selected granular fill” is a group of tightly controlled granular fill materials, each being defined to suit a specific end use (e.g. Class 6F1 to 6F5 are options for capping material);
- Class 7 “Selected cohesive fill” are a group of fill materials with greater than 15 % fines that can be utilized for particular purposes (e.g. Class 7E and 7F are fills for stabilization to form capping);
- Class 8 is a broad range of materials that can be used for trench fill;
- Class 9 “stabilised materials” are formed following the addition of a binder (and meet the requirements of prEN 16907-4).

Some intrinsic properties of fill materials are defined within the SHW classification system (e.g. SHW Table 6/2 defines grading requirements), although there is scope for the designer to identify additional classes of fill material with differing state properties if these are shown to satisfy the required engineering use. The SHW classification system requires the designer to determine the acceptable range of state properties to suit the intended end use for many of the classes of fill materials. This system has been developed to maximize the proportion of site won material as fill for the project, while continuing to facilitate acceptable earthwork construction. Therefore, the classification process continues through the fill design process described at H.2 below.

Table H.1 — Classification of earthworks materials in the UK by the SHW (reproduced from BS 6031:2009 Table 8)

Table 8 Classification of earthworks materials in the UK by the Highways Agency

Type	Class	Description	Typical use	
General granular fill	1A	Well graded granular material	General fill	
	1B	Uniformly graded granular material		
	1C	Coarse granular material		
General cohesive fill	2A	Wet cohesive material	General fill	
	2B	Dry cohesive material		
	2C	Stony cohesive material		
	2D	Silty cohesive material		
	2E	Reclaimed pfa cohesive material		
General chalk fill	3	Chalk	General fill	
Landscape fill	4	Various	Fill for landscape areas	
Topsoil fill	5A	Topsoil or turf existing on site	Topsoiling	
	5B	Imported topsoil		
Selected granular fill	6A	Selected well graded granular material	Below water	
	6B	Selected coarse granular material	Starter layer	
	6C	Selected uniformly graded granular material	Starter layer	
	6D	Selected uniformly graded granular material	Starter layer below pfa	
	6E	Selected granular material	For cement stabilization to form capping – class 9A	
	6F1	Selected granular material (fine grading)	Capping	
	6F2	Selected granular material (coarse grading)	Capping	
	6F3	Selected granular material recycled bituminous/asphaltic materials, etc.)	Capping	
	6F4	Selected/imported (unbound) granular material that conforms to BS EN 13285 (fine grading)	Capping	
	6F5	Selected/imported (unbound) granular material that conforms to BS EN 13285 (coarse grading)	Capping	
	6G	Selected granular material	Gabion filling	
	6H	Selected granular material	Drainage layer	For reinforced soil and anchored earth structures
	6I	Selected well graded granular material	Fill	
	6J	Selected uniformly graded granular material	Fill	
	6K	Selected granular material	Lower bedding for:	Corrugated steel buried structures
	6L	Selected uniformly graded granular material	Upper bedding for:	
	6M	Selected granular material	Surround to:	
	6N	Selected well graded granular material	Fill to structures	
	6P	Selected granular material	Fill to structures	
	6Q	Well graded, uniformly graded or coarse granular material	Overlying fill for corrugated steel buried structures	
	6R	Selected granular material	For stabilization with lime and cement to form capping – class 9F	
	6S	Selected well graded granular material	Filter layer below subbase	
Selected cohesive fill	7A	Selected cohesive material	Fill to structures	
	7B	Selected conditioned pfa cohesive material	Fill to structures and reinforced soil	
	7C	Selected wet cohesive material	Fill to reinforce soil	
	7D	Selected stony cohesive material	Fill to reinforce soil	
	7E	Selected cohesive material	For stabilization to form capping to:	Lime – class 9D
	7F	Selected silty cohesive material		Cement – class 9B
				Cement – class 9C
	7G	Selected conditioned pfa cohesive material	Overlying fill for corrugated steel buried structures	
	7H	Wet, dry, stony or silty cohesive material and chalk	For stabilization with lime and cement to form capping – class 9E	
	7I	Selected cohesive material		
Miscellaneous fill	8	Class 1, class 2 or class 3 material	Lower trench fill	
Stabilized materials	9A	Cement stabilized well graded granular material	Capping	
	9B	Cement stabilized silty cohesive material		
	9C	Cement stabilized conditioned pfa cohesive material		
	9D	Lime stabilized cohesive material		
	9E	Lime and cement stabilized cohesive material		
	9F	Lime and cement stabilized well graded material		

NOTE Clays and cohesive soils are shown in shaded rows.

H.3 Design of earthworks

H.3.1 General

The earthworks design process involves the identification of appropriate fill material properties to be included within the earthworks Specification to ensure that the completed embankment satisfies the required end use requirements for the earth structure. Therefore the main output of the earthworks fill material design process is the project specification.

BS 6031:2009 includes the following clauses that relate to the determination of the earthworks projects "Specification"; both reflect the approach required by prEN 16907-1:

- Clause 7 describes all aspects of the "Design of Earthworks", including a summary of the requirements for selection of the required properties of earthworks fill materials properties (at Clauses 7.6.2 and 7.6.4), which is a fundamental design stage required to enable the implementation of the SHW form of Specification;

- Clause 8 sets out the various approaches that can be implemented for the Specification of earthworks fill materials, with the requirements being based on either: method, end product or performance. Clause 8.2 sets out the requirements of the SHW approach, which are summarized below.

A core part of the SHW is the use of "method compaction" for most classes of fill, with "end-product" compaction being required for a number of particular classes of fill. The SHW provides earthworks designers with an introduction to the approach and the documents that need to be referenced for implementation on a project. The intention is to enable designers to utilize the SHW's well-established method compaction approach on a project wherever the designer considers that it will be an appropriate form of earthworks specification.

The defined "method compaction" requirements of layer thickness and number of passes for a wide range of different types of compaction plant were developed based on extensive research by the Transport Research Laboratory using full scale testing of plant for the geological strata and climatic conditions encountered in the British Isles [10]. The TRL research considered the significant variation in these geological and climatic conditions from the southeast of England to the northwest of Ireland or Scotland. The SHW system accommodates this wide range of conditions by giving the designer flexibility to determine the earthworks specification acceptability limits, based on relationship testing, for the fill materials available for use on the project. Details on the use of relationship testing for earthworks design purposes are provided by Nowak and Gilbert [9].

H.3.2 BS 6031:2009, Clause 8.2: Specification of earthworks by SHW approach

When the SHW [1] forms the basis of the earthworks specification, the document should preferably refer to the SHW rather than repeat the clauses from the SHW (e.g. "The Specification for earthworks shall be Series 600 of the Specification for Highway Works dated 20xx").

The content of the SHW [1] is updated on a regular basis by the Highways Agency. Users of the SHW should download the up to date version from: http://www.dft.gov.uk/ha/standards/mchw/.

The SHW [1] should be used to satisfy the compaction requirements of BS EN 1997-1:2004, 5.3.3 and the testing requirements of BS EN 1997-1:2004, 5.3.4.

Engineered fills which are used to produce suitably shaped landforms for building structures should be constructed to high standards to minimize the risk of ground movements causing damage to property built on shallow foundations. Specifications based on those developed for highway embankments are not necessarily appropriate for fills on which *buildings* will be founded, since acceptable settlement is likely to be significantly smaller for a building than for a road; hence a more stringent specification might be necessary than for highway purposes (see BS 6031:2009, 7.2).

H.3.3 SHW required documentation within project earthworks specification

The appropriate appendices should be completed by the earthworks Designer and provided with the Specification to enact several of the SHW [1] clauses. As a minimum, the following appendices should be provided:

- Appendix 1/5: Testing to be carried out by the Contractor (see Table H.2 below);
- Appendix 6/1 (including Table 6/1): Requirements for acceptability and testing, etc. of earthworks materials;
- Appendix 6/2: Requirements for dealing with unacceptable materials; and
- Appendix 6/3: Requirements for excavation, deposition, compaction.

Appendices 6/8, 6/12, 6/14 and 6/15 should also usually be provided. Other appendices should only be supplied when the specific works covered are proposed as part of the scheme. Reference to specific clauses in the DMRB [4] may also be provided.

H.3.4 Compaction requirements (classification, design and construction aspects)

SHW Table 6/1 indicates which classes of fill are appropriate for either “method” or “end product” compaction, and stipulates the appropriate method to be adopted where method compaction is appropriate. In some cases, the Designer may decide to modify the compaction requirements, in which case site trials to confirm the proposed approach may be necessary. Attempting to combine elements of both “method” and “end product” compaction for a class of fill is not appropriate.

The method compaction requirements that are stated within Table 6/4 of the SHW (see Table H.5 for an example) were developed based on extensive testing trials undertaken at the Transport Research Laboratory between 1945 and 1990 (as published in full by A W Parsons, [10]). Method compaction is designed to deliver 90 % compaction by BS 1377*, 2,5 kg compaction test for general fill and 95 % for most class 6 fills .The compactive effort stipulated in SHW [1] Table 6/4 is designed to produce an adequate state of compaction (less than 10 % air voids for many fills, and less than 5 % for certain class 6 fills) at a conservative (low) water content for the particular class of soil (see SHW [1] NG 612 for more details). See* BS 6031:2009, 7.6.4 *for further explanation.*

H.3.5 Alternative specifications

BS 6031:2009 sets the SHW [1] as the default specification for earthworks, but it does allow a project to use an alternative specification if the following minimum level of information is provided:

a) types of materials permitted for use in the earthworks together with material properties;

b) performance requirements to be met;

c) requirements for the disposal of unsuitable material;

d) requirements for placement, spreading and compaction of the earthworks materials;

e) requirements for the treatment of exposed surfaces;

f) requirements for the testing and verification of compliance.

H.3.6 Additional requirements for deep fill areas/buildings and structures

Collapse compression upon groundwater inundation is a major hazard for buildings and other structures on significant thicknesses of fill; therefore the specification of placement and compaction of the fill should be designed to eliminate collapse potential.

NOTE The risk of collapse upon inundation is particularly high where fill is placed below the potential groundwater level (e.g. infilling of a quarry), but is present at many other sites due to risk of inundation following a water main burst.

BS 6031:2009 reminds the designer that the collapse potential of some fills will not be eliminated despite the achievement of a field dry density equivalent to at least 95 % of the maximum dry density achieved using the BS 1377 2,5kg compaction test. In such cases, dry density should not be relied upon to provide an adequate measurement for compaction specification. Where there is an unacceptable risk of collapse upon inundation the specification should include a requirement for all fill to be compacted to < 5 % air voids. See Charles et al. [7] and BRE Digest 427 [8].

H.3.7 Selection of fill material properties (earthworks fill design)

Research at TRL led to the development of the compaction requirements of Table 6/4 of the SHW [1], which are intended to achieve an appropriate degree of compaction for the relevant classes of fill provided that the water content of the material is appropriate. Further guidance on the degree of compaction achieved using the methods specified in Table 6/4 is provided in BS 6031 [3] and HA44/91 [5] which describes how to set the parameters:

[http://www.dft.gov.uk/ha/standards/dmrb/vol4/section1/ha4491.pdf].

An important activity for every earthworks project is the selection of material properties for the fill; this is considered to be a design activity regardless of whether it is undertaken by a Contractor or a consultant. The material properties should be chosen to ensure that the engineering design assumptions are satisfied as well as addressing construction practicalities.

The material properties for earthworks fill should be selected to ensure that:

— the material can be trafficked, placed and compacted during construction of the earthworks;

— the earthworks will be stable during and after construction;

— excessive settlement or heave will not take place.

For the majority of fill materials, the acceptable material properties should be related to limits applied to either water content, MCV or shear strength (e.g. see Table 6/1 extract at Table H.3 below). It is strongly recommended that only one of these properties is used for a particular acceptability limit.

For most coarse soils, the upper and lower acceptability limits should be selected by reference to a particular ratio of dry density to the maximum dry density. The values are determined from dry density/water content relationship tests, which are illustrated in general terms in BS 6031:2009, Figure 9. The most commonly adopted criteria are 95 % of the maximum dry density determined from the 2,5 kg light dynamic compaction test or 90 % of the maximum dry density determined from the vibrating hammer test for bulk earthworks fill. A higher value up to 100 % of the maximum dry density is required for fill that will support structures where settlement is more critical. It is recommended that the air voids content at the proposed lower acceptability limit is checked to ensure that excessive air voids will not remain within the fill at the chosen compaction ratio; however, an air void content less than 10 % may not be feasible with some uniformly graded coarse soils.

It is important to note that the maximum dry density and optimum water content are not fundamental soil properties and the values are dependent on the compactive effort imparted to the material.

For fine soils the upper acceptability limit (see BS 6031:2009 Figure 10) e.g. minimum MCV, should be chosen in relation to the requirements for placement of the fill, stability of slopes, and settlement of the fill due to internal loading (see 7.6.3). These requirements may vary for different end uses of the earthworks, which will determine the fill properties of greatest importance, e.g. permeability for a flood bund, or *in situ* density for structural fill. The lower acceptability limit (minimum water content, maximum MCV or maximum shear strength) should be selected to reduce the air voids in the material to a value that will restrict the potential for excessive movement after compaction. A maximum of 10 % air voids for bulk earthworks fill and 5 % air voids for earthworks fill that is to support structures are commonly specified values. Research at TRL led to the development of the compaction requirements of Table 6/4 of the SHW [1], which are intended to achieve these values for the relevant classes of fill provided that the water content of the material is appropriate. Further guidance on the degree of compaction achieved using the methods specified in SHW Table 6/4 is provided in HA44/91.

The preferred method of specifying water limits on clays in the UK is the Moisture Condition Value (MCV), which is quick to measure on site and for which there is a substantial base of experience. The appropriate MCV values should be determined for the particular project based on site-specific laboratory relationship testing to relate MCV to fundamental properties. General guidance on appropriate ranges of MCV values based on experience across many sites is provided within BS 6031:2009 [3]. The MCV test is commonly used as the basis for quality control testing in the UK for fine soils (including sands), but it should not be used for stoney clays if there is insufficient matrix (typically less than 50 %–55 %) for the test and in such cases reliance on water content is necessary (Oliphant and Winter [6]).

Guidance on selection of classification and acceptability criteria and the appropriate frequency of testing is given in HA 44/91 [5] and BS 6031:2009 Clause 8 [3], see Table H2 below for a general summary. In addition to this guidance, the project specification and method of working on site should be developed to reflect local knowledge of materials and experience of particular equipment.

BS 6031:2009 *comments on some fill materials that require special consideration, for example:*

— *In the case of Class 2C fill materials of well graded soil (e.g. Glacial Till), the designer is encouraged to consider the implication of the fills grading (the relative proportion of gravel sized particles and soil matrix < 425 µm) and how this may influence the fill behaviour at a particular water content;*

— *many of the standard tests included in* BS 1377 *cannot be usefully employed on some of the UK soils primarily due to their coarse nature (>10 % of material is retained on the 37,5 mm sieve) requiring a flexible approach to identifying suitable acceptance criteria.*

Table H.2 — Classification and acceptability tests (reproduced from BS 6031:2009, Table 10)

Test	Applicable material type	Purpose	Reference
Water content	All	Classification/stabilization	BS 1377–2, BS 812–109
Atterberg limits	Cohesive	Classification	BS 1377–2
Particle size distribution	All	Acceptability/classification	BS 1377–2A)
MCV	Cohesive and/or some granular	Acceptability/trafficability	BS 1377–2, Clause 632 of SHW [1], TRRL LR 1034, TRRL LR 130, TRRL LR 90
Maximum density and optimum water content	Mainly granular	Acceptability/compatibility	BS 1377–2, BS 812–109
CBR	All except coarse granular	Trafficability/stabilization/ classification	BS 1377–2, BS 1924 (both parts)
Triaxial (quick)	Cohesive	Acceptability/trafficability	BS 1377–2
Chemical tests	All	Acceptability	BS 1377–2
Relationship testingB)	All	Acceptability	BS 1377–2

A) The requirements of BS 1377–2 may be added, to include all sieve sizes quoted in Table 6/2 of the SHW [1].

B) Testing soils at various water contents to study the change in soil properties.

When there are specific requirements to limit the internal settlement for large bodies of fill that will carry structures (as described at 7.6.3) then the approach of selection of design parameters beyond that which would normally be considered under the SHW [1] approach may be developed. One methodology that may be used is proposed in BRE Digest 427 [8], whereby:

— the water content upper and lower acceptability limits of the fill are chosen based on OMC from both the standard Proctor (2,5 kg rammer) and the modified Proctor (4,5 kg rammer) compaction tests (i.e. relatively dry material for fine soils), see Nowak and Gilbert [36] for further details; and

— the method of compaction is selected to ensure heavy compaction is delivered (which is likely to be in excess of the SHW standard methods); and

— the earthworks are monitored to ensure a high *in situ* density and low air voids are achieved.

Further information on the approach required to select material properties for earthworks fill is provided in BS 6031:2009 Clause 7.6.4 (the first half of which is reproduced as the text given above).

Particular design requirements associated with treatment of fill with lime or cement binders is set out within HA74/07 [11].

H.3.8 Extracts from core tables of UK Specification for Highway Works (SHW)

The following extracts from the core tables of the SHW have been included to help illustrate the layout of the system that is used in the UK. These are only short extracts; the reader shall refer to the original document for the full version which can be obtained freely from the Highways Agencies website: *http://www.dft.gov.uk/ha/standards/mchw/*.

One page extracts are provided here of each of the following tables (value in brackets shows the length of the full document):

- Table 6/1: Acceptable Earthworks Materials: Classification and Compaction Requirements (original is 30 pages, extract included as Table H.3 below);
- Table 6/2: Grading Requirements for Acceptable Earthworks Materials (original is 2 pages, extract included as Table H.4 below); and
- Table 6/4: Method Compaction for Earthworks Materials: Plant and Methods (original is 4 pages, extract included as Table H.5 below).

It shall be recognized that these tables form part of a full Specification and shall be read with in conjunction with the 600 series clauses of the SHW. Guidance on the completion of the project earthworks specification appendices are provided in *Notes for Guidance to the Specification for Highway Works* [2].

The Designer is required to finalise Table 6/1 for the project Specification based on the design process described above. The designer shall assess the properties to be used to control the earthworks and is required to determine each of the Acceptable Limits that are marked “App 6/1” and update the table with project specific values. If the earthworks are to be controlled by water content, then this will normally be achieved relative to the optimum water content, in which case the required compaction test will need to be inserted into the project specific Table 6/1.

Table H.3 — extract of Table 6/1 (reproduced from SHW, November 2009)

Class				General Material Description	Typical Use	Permitted Constituents (All Subject to Requirements of Clause 601 and Appendix 6/1)	Material Properties Required for Acceptability (In Addition to Requirements on Use of Fill Materials in Clause 601 and Testing in Clause 631)				Compaction Requirements in Clause 612	Class		
							Property (See Exceptions in Previous Column)	Defined and Tested in Accordance with:	Acceptable Limits Within:					
									Lower	Upper				
GENERAL COHESIVE FILL	2	C	-	Stony cohesive material	General Fill	Any material, or combination of materials, other than chalk	(i) grading	BS 1377 : part 2	Tab 6/2	Tab 6/2	Tab 6/4 Method 2	2	C	-
							(ii) plastic limit (PL)	BS 1377 : part 2	-	-				
							(iii) mc	BS 1377 : Part 2	App 6/1	App 6/1				
							(iv) MCV	Clause 632	App 6/1	-				
							(v) Undrained shear strength of remoulded material	Clause 633	App 6/1	-				
	2	D	-	Silty cohesive material	General Fill	Any material, or combination of materials, other than chalk	(i) grading	BS 1377 : Part 2	Tab 6/2	Tab 6/2	Tab 6/4 Method 3	2	D	-
							(ii) mc	BS 1377 : Part 2	App 6/1	App 6/1				
							(iii) MCV	Clause 632	App 6/1	App 6/1				
							(iv) undrained shear strength of remoulded material	Clause 633	App 6/1	App 6/1				
	2	E	-	Reclaimed pulverised fuel ash cohesive material	General Fill	Reclaimed material from lagoon or stockpile containing not more than 20% furnace bottom ash	(i) mc	BS 1377 : Part 2	To enable compaction to Clause 612		End product 95% of maximum dry density of BS 1377 : Part 4 (2.5 kg rammer method)	2	E	-
							(ii) bulk density	BS 1377 : Part 9	App 6/1	App 6/1				

Table H.4 — extract of Table 6/2 (reproduced from SHW, November 2009)

Percentage by Mass Passing the Size Shown																					
Class	**Size (mm)**		**Size(mm) BS Series**													**Size (microns) BS Series**				**Size (micr-ons)**	**Class**
	500	**300**	**125**	**90**	**75**	**37.5**	**28**	**20**	**14**	**10**	**6.3**	**5**	**3.35**	**2**	**1.18**	**600**	**300**	**150**	**63**	**2**	
1A		100	95-100																<15		1A
1B			100																<15		1B
1C	100		10-95													0-25			<15		1C
2A & 2B			100											80-100					15-100		2A & 2B
2C			100											15-80					15-80		2C
2D			100																80-100	0-20	2D
6A	100									0-100		0-85				0-45			0-5		6A
6B	100		0-10																		6B
6C			100			0-100					0-100		0-35	0-10		0-2					6C
6D										100		89-100		60-100	30-100	15-80	5-48	0-15 except 0-20 for crushed rock			6D
6E & 6R			100	85-100						25-100						10-100			<15		6E & 2R
6F1					100	75-100				40-95		30-85				10-50			<15		6F1
6F2			100	80-100	65-100	45-100				15-60		10-45				0-25			0-12		6F2
6F3			100	80-100	65-100	45-100				15-60		10-45				0-25			0-12		6F3
6H								100				60-100			15-45	0-25		0-5			6H
6I & 6J			100		85-100				25-100					15-100		9-100			<15		6I & 6J
6K								100											0-10		6K
6L										100		89-100		60-100	30-100	15-100	5-70	0-15 except 0-20 for crushed rock			6L

Table H.5 — extract of Table 6/4 (reproduced from SHW, November 2009)

Type of Compaction Plant	Ref No.	Category	Method 1		Method 2		Method 3		Method 4		Method 5		Method 6		
			D	N#	D	N#	D	N#	D	N	D	N	N for D = 110 mm	N for D = 150 mm	N for D = 250 mm
Smoothed wheeled roller (or vibratory roller operating without vibration)		Mass per metre width of roll:													
	1	over 2100 kg up to 2700 kg	125	8	125	10	125	10*	175	4	unsuitable		unsuitable	unsuitable	unsuitable
	2	over 2700 kg up to 5400 kg	125	6	125	8	125	8*	200	4	unsuitable		16	unsuitable	unsuitable
	3	over 5400 kg	150	4	150	8	unsuitable		300	4	unsuitable		8	16	unsuitable
Grid roller		Mass per metre width of roll:													
	1	over 2700 kg up to 5400 kg	150	10	unsuitable		150	10	250	4	unsuitable		unsuitable	unsuitable	unsuitable
	2	over 5400 kg up to 8000 kg	150	8	125	12	unsuitable		325	4	unsuitable		20	unsuitable	unsuitable
	3	over 8000 kg	150	4	150	12	unsuitable		400	4	unsuitable		12	20	unsuitable
Deadweight tamping roller		Mass per metre width of roll:													
	1	over 4000 kg up to 6000 kg	225	4	150	12	250	4	350	4	unsuitable		12	20	unsuitable
	2	over 6000 kg	300	5	200	12	300	3	400	4	unsuitable		8	12	20
Pneumatic-tyred roller		Mass per wheel:													
	1	over 1000 kg up to 1500 kg	125	6	unsuitable		150	10*	240	4	unsuitable		unsuitable	unsuitable	unsuitable
	2	over 1500 kg up to 2000 kg	150	5	unsuitable		unsuitable		300	4	unsuitable		unsuitable	unsuitable	unsuitable
	3	over 2000 kg up to 2500 kg	175	4	125	12	unsuitable		350	4	unsuitable		unsuitable	unsuitable	unsuitable
	4	over 2500 kg up to 4000 kg	225	4	125	10	unsuitable		400	4	unsuitable		unsuitable	unsuitable	unsuitable
	5	over 4000 kg up to 6000 kg	300	4	125	10	unsuitable		unsuitable		unsuitable		12	unsuitable	unsuitable
	6	over 6000 kg up to 8000 kg	350	4	150	8	unsuitable		unsuitable		unsuitable		12	unsuitable	unsuitable
	7	over 8000 kg up to 12000 kg	400	4	150	8	unsuitable		unsuitable		unsuitable		10	16	unsuitable
	8	over 12000 kg	450	4	175	6	unsuitable		unsuitable		unsuitable		8	12	unsuitable
Vibratory tamping roller		Mass per metre width of a vibrating roll:													
	1	over 700 kg up to 1300 kg	100	12	100	12	150	12	100	10	unsuitable		unsuitable	unsuitable	unsuitable
	2	over 1300 kg up to 1800 kg	125	12	125	12	175	12*	175	8	unsuitable		12	unsuitable	unsuitable
	3	over 1800 kg up to 2300 kg	150	12	150	12	200	12*	unsuitable		unsuitable		8	12	unsuitable
	4	over 2300 kg up to 2900 kg	150	9	150	9	250	12*	unsuitable		400	5	6	10	unsuitable
	5	over 2900 kg up to 3600 kg	200	9	200	9	275	12*	unsuitable		500	6	6	10	unsuitable
	6	over 3600 kg up to 4300 kg	225	9	225	9	300	12*	unsuitable		600	6	4	8	unsuitable
	7	over 4300 kg up to 5000 kg	250	9	250	9	300	9*	unsuitable		700	6	3	7	12
	8	over 5000 kg	275	9	275	9	300	7*	unsuitable		800	6	3	6	10

The Method number shall be as stated for the class of fill in Table 6/1, “D” is maximum depth of the compacted layer and “N” is the minimum number of passes (see SHW cl. 612 for full details and plant operation requirements).

H.4 Control of earthworks during construction

BS 6031:2009, Clause 9 sets out general requirements for management of earthworks construction, an important part of which is the Quality Assurance/Quality Control (QA/QC) testing to be undertaken during construction which shall be in accordance with the project earthworks specification (see H.3 above). This earthworks control testing will include testing for both fill classification and construction control.

The Designer should stipulate the testing requirements for earthworks materials during construction as part of the QA/QC process, including any source approval testing and routine fill control testing during the works. Under the SHW this information is presented within Appendix 1/5 which may be in the form presented in Table NG1/1 of SHW [1]. The designer should include either the frequency or number of tests dependent on the size or duration of the works being undertaken.

All earthworks materials will be controlled by testing to check the acceptability of the fill material prior to placement in the works, to confirm compliance with the project specification. The main difference in quality control approach between the two main forms of compaction control are as follows:

- Earthworks managed by method compaction focus on checking that the number of passes, and resulting compacted layer thickness, satisfy the compaction method for the type of compaction plant that is defined at SHW Table 6/4. In addition, a limited number of *in situ* density tests are undertaken to check that the standard compaction method is appropriate for the fill and site conditions.

- Fill materials managed by end product compaction are simply tested for *in situ* dry density and/or stiffness of the compacted fill, with tests undertaken at regular intervals through the earthwork to check that acceptable results are consistently achieved.

The use of full scale site compaction trials at the start of the construction works is encouraged to confirm that the intended methods of working achieve the expected results.

Detailed records shall be maintained of all the QA/QC testing undertaken, along with details of the location of tests within the works and relevant site observations. In the UK, the approach of summarizing the construction records within a Geotechnical Feedback Report is encouraged to capture "lessons learned" in order to improve future methods of working.

H.5 References

[1] Manual of Contract Documents for Highway Works, Volume 1 – Specification for Highway Works, Series 600 – Earthworks. Highways Agency. (www.standardsforhighways.co.uk)

[2] Manual of Contract Documents for Highway Works, Volume 2 – Notes for Guidance on the Specification for Highway Works. Highways Agency. (www.standardsforhighways.co.uk)

[3] BS 6031:2009 Code of Practice for Earthworks, BSi.

[4] Highways Agency. Design Manual for Roads and Bridges.

[5] Highways Agency. HA 44/91, Design Manual for Roads and Bridges, Volume 4 Geotechnics and Drainage, Section 1 Earthworks, Part 1 Design and Preparation of Contract Documents (including Amendment No. 1 1995). 1995.

[6] Oliphant J. and Winter M.G. Limits of use of the moisture condition apparatus. Proc ICE Transport. Thomas Telford. 1992.

[7] Charles J.A., Skinner H.D. and Watts K.S. The specification of fills to support buildings on shallow foundations: the "95% fixation". Ground Engineering, 31, 1, pp 29-33. 1998.

[8] BRE Digest 427. Low-rise buildings on fill, Part 3 Engineered fill. 1998.

[9] Nowak P. and Gilbert P. Earthworks: a guide, 2nd edition, ICE Publishing. 2015.

[10] Parsons A.W. (1992), Compaction of Soils and Granular Materials: A review of research performed at the Transport Research Laboratory, HMSO.

[11] Highways Agency. HA74/07: Treatment of fill and capping materials using either lime or cement or both. HMSO. 2007.