



BSI Standards Publication

Earthworks

Part 1: Principles and general rules

National foreword

This British Standard is the UK implementation of EN 16907-1:2018.

Annex H is an informative annex which provides a summary of national practice within the United Kingdom. The UK committee draws users' attention to Table H.3, Design of earthworks, where some boxes are blank as text has been inadvertently omitted. In addition, Table H.4 contains two values which the UK committee suggests are incorrect: under class 6D, size 300 (microns), the range should be 5-48, and under class 6L, size 150 (microns), the range should be 0-15. The UK committee advises users of BS EN 16907-1:2018 that both tables are reproduced with the correct values in the *Specification for Highway Works (SHW), Series 0600 — Earthworks*, which can be obtained from the Highways England website: <http://www.dft.gov.uk/ha/standards/mchw/>

The UK participation in its preparation was entrusted to Technical Committee B/526/-/1, Earthworks.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Erdarbeiten - Teil 1: Grundsätze und allgemeine Regeln

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European foreword

This document (EN 16907-1:2018) has been prepared by Technical Committee CEN/TC 396 “Earthworks”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2019, and conflicting national standards shall be withdrawn at the latest by June 2019.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document is one of the European Standards within the framework series of EN 16907 on *Earthworks*. 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 collectively as a group of standards for executing earthworks. The full set of Parts is as follows:

- EN 16907-1 *Earthworks - Part 1: Principles and general rules* (this document);
- EN 16907-2 *Earthworks - Part 2: Classification of materials*;
- EN 16907-3 *Earthworks - Part 3: Construction procedures*;
- EN 16907-4 *Earthworks - Part 4: Soil treatment with lime and/or hydraulic binders*;
- EN 16907-5 *Earthworks - Part 5: Quality control*;
- EN 16907-6 *Earthworks - Part 6: Land reclamation earthworks using dredged hydraulic fill*;
- EN 16907-7 *Earthworks - Part 7: Hydraulic placement of extractive waste*.

Within this standard, references to specific parts of the standard are written by reference the full reference (e.g. “EN 16907-2”).

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. 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.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

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 will be used together with Part 1.

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;
- noise barriers, visual barrier, and other non-load bearing earthworks;
- landscaping embankments;
- backfilling of open mines and quarries;
- tailings dams;

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

This standard is applicable to all types of earth-structures, except the cases 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.

This standard does not cover ground improvement beneath an earth-structure by techniques such as piling, jet grouting, deep soil mixing, vertical drains or stone columns.

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 a short period by a European Standard. This European Standard gives therefore basic rules to reach the aims described above. Informative Annexes B to H of this document give examples of national practices following these rules.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. 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, *Eurocode 7 - Geotechnical design - Part 2: Ground investigation and testing*

EN 16907-2, *Earthworks - Part 2: Classification of materials*

EN 16907-3, *Earthworks - Part 3: Construction procedures*

EN 16907-4, *Earthworks - Part 4: Soil treatment with lime and/or hydraulic binders*

EN 16907-5, *Earthworks - Part 5: Quality control*

EN 16907-6, *Earthworks - Part 6: Land reclamation earthworks using dredged hydraulic fill*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

Note 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 A.

3.1 Definitions

3.1.1

air void content

ratio of the volume of air to the total volume of the soil

3.1.2

binder

product or combination of products which, when mixed with a material, provides either a short-term or a long term enhancement of the properties of the material

3.1.3

bulking

volume change of a soil mass due to handling (normally a positive volume change upon excavation)

3.1.4

capping layer

specific transition layer, part of the upper zone of the fill, placed below the superstructure. The capping layer is part of the earth structure

3.1.5

classification

definition of classes and assigning of materials to classes with similar properties for earthworks

3.1.6

compaction

densification of fill material by mechanical process, to obtain prescribed properties of the fill

3.1.7

compactive effort

overall measure of the physical exertion applied to compact a layer of fill, which reflects : compactor mass/m², number of passes, speed of the roller, frequency of vibration and layer thickness

3.1.8

cut or cutting

linear earth-structure formed by the process of excavation

3.1.9

degree of compaction (of fill)

ratio between *in situ* dry density of compacted fill material and maximum dry density obtained from a standard laboratory compaction test

3.1.10

degree of saturation

ratio of the pore water volume to the volume of voids

3.1.11

description

identification and naming of a given material and its physical and soil mechanical properties that are relevant for earthwork purposes

3.1.12

design of earth-structure

defining the civil engineering structure under EN 1997 series to meet the functional requirements for future use

3.1.13

design of earthworks

defining the construction process to produce a specified earth-structure

3.1.14

dredging

excavation activity or operation usually carried out at least partly underwater, in shallow seas or fresh water areas with the purpose of gathering up bottom sediments and placing them at a different location

3.1.15

dry density

mass of the solid particles divided by the total volume of a sample

3.1.16

earth-structure

civil engineering structure, made of soils, rocks, by-products or recycled materials, resulting from earthworks (cut, fill, infill)

3.1.17

earthworks

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

3.1.18**earthworks constructor**

person or organization in charge of executing earthworks

3.1.19**earthworks designer**

person or organization in charge of designing earthworks

3.1.20**embankment**

common name for an earth-structure formed by the process of filling to form a free standing earth structure (including linear features and nonlinear platforms)

3.1.21**end product specification**

specification requiring earthworks to be constructed to achieve specified engineering criteria related to the compacted fill

3.1.22**excavation**

general term used both for the process of excavating the ground or for the resulting change in the ground surface either for a temporary excavation or permanent earth structure

3.1.23**extractive waste**

mineral wastes derived from mineral extraction operations

3.1.24**fill**

collective term used in this standard to describe all earth-structures formed by the placement of fill material in a controlled manner for an engineering purpose (including embankment, infill, platform, etc.)

3.1.25**fill material**

material used for the construction of a fill

3.1.26**fill zone**

subdivision of a fill (or part of an earth-structure), such as the base, the core, the shoulders and the upper zone

3.1.27**filling**

process of placing fill material to form a temporary or permanent earth structure

3.1.28**formation level**

prepared surface on which the fill or the superstructure is built

3.1.29

hydraulic fill

material placed in a liquid form, as a mixture of soil particles and water, in a deliberate manner so that the soil particles accumulate as a deposit, and densify as further fill is placed above to create a body of fill

3.1.30

infill

earth structure formed by filling a void or hollow in a controlled manner to form a body of engineered fill that is not free standing (including an excavation infill, filling behind an embankment for the purposes of land reclamation, mine infill, etc.)

3.1.31

materials

soils, rocks, industrial by-products and recycled mineral materials used during earthworks for construction of earth-structures. In this standard, materials do not include binders, geosynthetics and other materials, which are designated by their own name

3.1.32

mattressing

behaviour of soil that is too wet during compaction, resulting in the formation of waves, creating instability of the compaction plant and preventing further compaction

3.1.33

maximum dry density

maximum value of the dry density obtained in the reference compaction test (Proctor or Modified Proctor, Vibrating Hammer Compaction or any other compaction test). This value is related to a water content that is also known as the optimum water content

3.1.34

method specification

specification requiring to produce and place earth-structures using specified materials, specific types of equipment and methods

3.1.35

natural soil or rock

soil or rock that is either in its original geological setting or has been excavated, but has not been fundamentally modified by human activity other than earthworks processes such as excavation, screening and crushing, drying (or those processes described in this standard).

3.1.36

non-structural fill

fill that is not going to support any infrastructure

3.1.37

optimum water content

water content at which a specified compactive effort can compact a soil mass to its maximum dry density

3.1.38

over compaction

excessive compaction, by load intensity or duration, resulting in excess porewater pressure leading to unacceptable fill properties (e.g. mattressing)

3.1.39**performance specification**

specification requiring the works to be defined relative to long-term project requirements, which are commonly set at a relatively high level

3.1.40**properties**

physical, mechanical and chemical attributes of a material

3.1.41**quality assurance**

planned and systematic actions necessary to provide confidence that the earth-structure will perform satisfactorily in service i.e. that it has been constructed to the specified requirements

3.1.42**quality control**

system used to monitor, assess and adjust construction/execution processes to ensure that the final product will meet the specified level of quality

3.1.43**secondary fill material**

material that has been fundamentally changed by human activity for one purpose and then is reused as an earthworks fill material (this may include: recycled material, by-product, secondary aggregate, etc.)

3.1.44**specification (technical specification)**

document or set of clauses that states the technical requirements for construction and control of the earthworks (to be read in conjunction with the project drawings)

3.1.45**suitable material**

fill material where the soil properties prior to compaction satisfy the requirements of the earthworks technical specification and the material is in a state that can be placed within the earthworks ready for compaction

3.1.46**superstructure**

civil engineering structure placed on top of a fill (examples of superstructures are: road pavement, rail track, buildings, gantries, etc.)

3.1.47**trafficability**

ability of a material surface to support the passage of earthworks equipment

3.1.48**treated fill material**

fill material that has been modified by the addition of a binder

3.1.49**unsuitable material**

fill material that is not suitable for use in its current state because the soil properties prior to compaction do not satisfy the requirements of the earthworks technical specification. These materials may become suitable after treatment to adjust the soil properties

3.1.50

water content

ratio of the weight of water contained in a particular sample to the weight of the dry ground

3.2 Abbreviations and symbols

Abbreviations and symbols are listed below in alphabetic order of abbreviations, then symbols.

Abbreviations

CBR	CBR test California Bearing Ratio test
CBR _i	Immersed (soaked) CBR test
CCC	Continuous compaction control
CPT	Static cone penetrometer test
DG	Degradability test
DPT	Dynamic cone penetration test
FR	Fragmentability test
IPI	IPI test or Immediate Bearing Index test
LA	Los Angeles test
MCV	Moisture condition value test
MDE	Micro-Deval test
SPT	Standard penetration test

Symbols for parameters

a_v	Air void ratio	dimensionless
c'	Effective cohesion	kPa
C_c	Coefficient of curvature	dimensionless
C_{CaCO_3}	Calcium carbonate content	dimensionless (%)
C_{OM}	Organic matter content	dimensionless (%)
C_u	Coefficient of uniformity	dimensionless
C_{salt}	Soluble salts content	dimensionless (%)
C_x	Mass percentage of particles finer than x (mm)	dimensionless (%)
D_{max}	Maximum dimension of the largest elements contained in the soil	mm
D_{Pr}	Degree of compaction $\rho_d/\rho_{dmax} = \gamma_d/\gamma_{dmax}$	dimensionless

D_x	Particle size at which x % are finer	mm
e	void ratio	dimensionless
E	Modulus of elasticity	MPa
E_c	Modulus of elasticity in compression	
E_{it}	Modulus of elasticity in indirect tension	
E_t	Modulus of elasticity in direct tension	
$E_{V1} (M_1)$	Plate load test modulus E_{V1}	
$E_{V2} (M_2)$	Plate load test modulus E_{V2}	
G_v	Volumetric swelling	
I_c	Consistency index	
I_{CBR}	California bearing ratio index CBR index	
I_{CBRi}	Immerged or soaked CBR index	
I_D	Density index	
I_{DG}	Coefficient of degradability	
I_{FR}	Coefficient of fragmentability	
I_{FS}	Coefficient of friability for fine aggregate	
I_{IPI}	Immediate bearing index IPI index	
I_m	Thornwaithe index	
I_{MCV}	Moisture condition value index	
I_p	Plasticity index	
I_r	Strength after immersion ratio (R_i/R)	
I_{s50}	Point load index	
$LA^{(1)}$ or C_{LA}	Los Angeles coefficient (1) used in test standard EN 1097-2	
L_s	Linear swelling amplitude (CBR mould)	
$MDE^{(2)}$ or C_{MDE}	Micro-Deval coefficient (2) used in test standard EN 1097-1	
n	Porosity	
n_a	Air void content = air volume/total volume	
P	Degree of pulverization	
R	Compressive or tensile strength	
R_c	Compressive strength	
R_i	Compressive or tensile strength after immersion in water	
R_{it}	Indirect tensile strength	
R_t	Tensile strength	

S_r	Degree of saturation
V_{BS}	Methylene blue value (fraction 0/50 mm)
V_p	Compression wave velocity
V_s	Shear wave velocity
w	Water content
w_L	Liquid limit
w_n	Natural water content
w_{OPM}	Optimum water content (Modified Proctor test)
w_{OPN}	Optimum water content (Proctor test)
w_P	Plastic limit
w_S	Shrinkage limit
$x \% \rho_{dmaxOPN}$	Fraction x% of the maximum dry density on the reference Proctor curve
ϵ_{coll}	Linear collapse strain (oedometer)
ϵ_{sw} or ϵ_g	Linear swelling strain
ϵ_{vsw} or ϵ_{vg}	Volumetric swelling strain
γ	Weight density (unit weight)
γ_b	Bulk weight density
γ_d	Dry weight density
γ_{dn}	<i>In situ</i> dry weight density
$\gamma_{dmaxOPM}$	Maximum dry weight density at optimum water content in Modified Proctor test (OPM)
$\gamma_{dmaxOPN}$	Maximum dry weight density at optimum water content in Proctor test (OPN)
ν	Poisson's ratio
ϕ'	Angle of internal friction
P (Angle of internal friction degree)	Density
ρ	
ρ_b	Bulk density
ρ_d	Dry density
$\rho_{dmaxOPM}$	Maximum dry (mass) density at optimum water content in Modified Proctor test (OPM)
$\rho_{dmaxOPN}$	Maximum dry (mass) density at optimum water content in Proctor test (OPN)
ρ_{dn}	<i>In situ</i> dry density

4 Principles of earthworks design and execution

4.1 General

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

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:
 - planning of the earth-structures to be built;
 - site investigations and classification of materials (Clause 5 of this standard and EN 16907-2:2017, Clause 5);
 - assessment of the compatibility of these materials with the required properties of the earth-structure (Clauses 6, 7, 8 and 9);
 - selection of a construction procedure (EN 16907-1, EN 16907-3, EN 16907-6 and EN 16907-7);
 - optimization of earthworks at the scale of the whole project (Clause 11);
 - specifications for executing the works (construction procedure, monitoring, quality control) (EN 16907-1, EN 16907-3, EN 16907-5, EN 16907-6 and EN 16907-7);
- execution of works (construction):
 - construction of earth structure on site;
 - checking the design assumptions;
 - execution of works as specified;
 - monitoring of the ground (e.g. slope stability);
 - quality control / quality assurance;
 - checking the characteristics of the completed earth-structure versus the requirements, leading to the acceptance of the results of the earthworks.

4.3 Instructions for the execution of works

The earthworks design process shall produce detailed instructions to be satisfied during the execution of works. This standard sets out earthworks design requirements related to the determination of these requirements. The following list gives examples of the items or construction requirements that may be generated as part of the earthworks design process, the instructions will be determined to suit the particular project (this list is not intended to be exhaustive):

- site preparation:
 - details of existing buried services, foundations, structures, buildings and obstructions that may be impacted by the earthworks, and associated restrictions;
 - restrictions related to surface water and ground water;
 - earthworks drainage requirements.
- Materials:
 - description and classification of soils, rocks and other materials, in accordance with EN 16907-2
 - acceptable properties and conditions of fill materials for use in the earthworks;
 - constraints concerning the use of specific materials;
 - treatment and processing of materials to enable use as fill material;
- for fills and cuttings:
 - quantity (volume), type, position, dimensions and structure of the earth-structures;
 - quantity, type, position, dimensions, formations and purpose of construction pits, borrow pits and trenches, including minimum dimensions of the working space;
 - installation of geosynthetic material;
 - preparation of surfaces prior to the placement of fill;
 - measures to prevent deterioration of the works including earthworks drainage
- Quality control and quality assurance requirements:
 - compaction requirements and testing to demonstrate compliance with the Technical Specification;
 - identification of the acceptable construction tolerances for defined surfaces such as formation level and layer thicknesses
 - guidelines resulting from technical reports and analysis, and requirements to be addressed during construction;
- Temporary and permanent protection measures:
 - protection for construction pits and trenches, embankments and slopes;

- protective layer above formation level, thickness of the protective layer and timing of removal;
- Logistical aspects:
 - permitted transportation routes, required conditions and potential restrictions on use;
 - storage / stockpile areas available, and any requirements for storage conditions;
 - time constraints imposed on the construction process, such as permissible operating temperatures, working hours, acceptable noise levels, monitored hold periods.

4.4 Relationship between earthworks and earth-structure design

The design of earthworks relates to the selections of fill material properties and specification of the requirements for the earthworks construction process to ensure that the completed earth-structure satisfies the geotechnical design.

The design of earth-structures in terms of stability and deformations is ruled by EN 1997 series (Eurocode 7) and other relevant standards. Geotechnical and structural design produces the requirements put on the properties and functions of the completed structure (for example: 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 fill with the required properties, or a stable cut. This decision process includes the characterization of natural ground and the choice of suitable equipment and rules to plan extraction, transport, compaction and control of the materials. The products of this design include: technical specifications, drawings, 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 geometry and properties of the completed structure;
- the nature and state of materials to be handled (EN 16907-2);
- the hydrological, hydrogeological and meteorological contexts;
- the importance of the earth-structure to be built and the consequences of failure;
- the type of equipment available to perform the works (EN 16907-3);
- the possibilities offered by material treatment for fill construction (EN 16907-4);

The earthworks designer prepares technical specifications for executing the works (EN 16907-3, EN 16907-4, EN 16907-6, EN 16907-7). The earthworks specification sets out requirements that are to be satisfied during construction, on various different topics that may include some of the following:

- monitoring and quality control procedures,
- the acceptable properties of fill materials, and how these shall be checked during execution of the works,

- the mechanical process used for extraction, transport, layering, and compaction, and if appropriate any processing or treatment to modify the fill materials properties;
- the areas where fills may be constructed;
- the location of temporary or permanent surplus material disposal areas;
- the schedule of operations;
- the climatic restrictions, for example how to proceed at temperatures close to freezing, working restrictions relating to rainfall / wet weather;
- 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 may 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. 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 Sustainable development and environmental considerations for earthworks

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 optimizing the use of materials from the site, and where appropriate the use of secondary materials;
- the limitation of heavy vehicles traffic to bring materials to the construction site;
- the reduction of the externalisation of stockpiles, borrow pits and off-site disposal of materials;
- 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. 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,
- biodiversity.

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 secondary materials should be considered from the beginning of a project to maximize chances of re-use with respect to existing laws.

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 such as:

- unknown or unexpected site conditions;
- 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);
- the impact of natural hazards (for example earthquakes, floods, etc);

- the impact of unpredictable site conditions (for example geological stratigraphy and faults);
- the presence of contaminated ground.

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 earthwork processes

Earthworks encompass a large range of activities, which cannot be covered by a unique set of rules. This standard provides guidance and requirements for four groups of earthwork activity as follows:

- construction of fills (Clause 6 of this standard and EN 16907-3, EN 16907-4, and EN 16907-5);
- execution of cuts and excavations (Clause 7 of this standard and EN 16907-3);
- hydraulic placement of dredged material (Clause 8 of this standard and EN 16907-6);
- hydraulic placement of soils and mineral waste (Clause 9 of this standard and EN 16907-7).

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 materials for earthworks should cover:

- geological conditions (including seismicity), and the type of material (soils, rocks and other materials);
- the presence of pollutants;
- the presence of organic matter and evolving or reactive minerals (such as gypsum, soluble salts, sulfur, sulfide and sulfate specifically.);
- all necessary information to classify the materials (EN 16907-2)
- information on the initial state of natural soils and rocks
- the determination of the optimum compaction characteristics for fill materials;
- when necessary, an estimate of the stiffness, strength and permeability of the compacted material;
- any other information required for the project.

In addition the designer will need information about the groundwater conditions and potential flow into excavations (see Clause 5.2.3).

5.2 Coordination of ground investigations

5.2.1 General

The requirements of EN 1997-2 shall be satisfied. Ground investigations for an earthworks project shall provide adequate and sufficient information for the design and construction of the earthworks, including the temporary slopes and any temporary 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, 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.

Where possible the desk study for an earthwork project should seek to obtain information from previous projects and published data about the earthworks performance of the fill materials, and potential adverse influence of the geological and hydrogeological conditions on earthworks construction.

Ground 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 natural 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: “cuttings” and “fills”. These structures shall be designed following the rules of EN 1997-1, which consider stability, deformations and durability of each structure.

EN 1997-2 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 ground 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.

The state of the materials is assessed from observations of the ground and measurements of soil and rock properties described in Clause 5.3 *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. An adequate amount of soil should be recovered to enable testing at a set of water contents, allowing assessment of the acceptable range of water content of the material for efficient compaction. This sampling requirement favours trial pitting to enable recovery of large quantities of specific strata by multiple bulk disturbed samples. Specific studies may then be made for the appropriate treatment of soil material falling outside of this acceptable water content range. When the material cannot be tested in the laboratory because of the size of the individual particles or blocks, *in situ* full scale compaction tests can be used (see Clause 6.1).

For excavation, information is needed on the strength of soil and rock, which affects the choice 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 geotechnical investigation (including inspection of rock exposures) and analysis in combination with geophysical investigation. When relevant, the stiffness and alterability of ground shall be assessed by means of laboratory tests or geophysics.

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 ground investigations.

The location and spacing between investigation points and investigation depth shall consider the guidance within EN 1997-2. The earthworks designer may determine that it is appropriate to adapt these requirements to reflect the particular requirements of an earthworks project. The depth of the investigations shall ensure that all layers and ground conditions that impact the earthworks are investigated.

The investigations regarding earthworks and other structures should be coordinated to obtain the information required for the different elements of the project.

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 estimation of 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 facilitate clear communication by describing soils, rocks and other materials in accordance with standard descriptive systems.

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

EN 16907-2 gives rules for the description and classification of soils and rocks and other materials used for earthworks.

EN 16907-2 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, fracture state, etc.;
- classification by parameters of “intrinsic properties”, which are material properties that cannot readily be changed and are 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. Project earthworks technical specification fill groups are commonly defined based on intrinsic properties;
- classification based on parameters of “state properties” which are readily changed by earthworks processes, 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 particular zones within an earth-structure (e.g. general fill, capping layer).

As indicated in Clause 6, 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 trials are used for assessing materials of unknown behaviour, or the use of new equipment or procedures. The trials may focus on the nature of the ground mass and the fill material response to compaction rather than rely entirely on existing classification systems. A list of commonly used test standards for identification and classification of fill materials is provided in EN 16907-2.

6 Design of earthworks for fills

6.1 Introduction

The earthworks project specifies the execution procedures (e.g. 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 that conform to the requirements (or assumptions) of the earth-structures project.

Since earthworks construction is frequently controlled using density of the compacted fill materials, there is a need to link density to the mechanical properties of the resulting fill, in terms of stability

(shear resistance), deformations (deformability) and water tightness (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, industrial 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, transport, treatment, spreading in layers, compaction), the available equipment, the nature and initial state of the soil/rock, the climate, and the desired final state;
- optimizing the earthworks project in terms of equipment use, limitation of transport, protection of the environment, sustainable development, cost, duration of works;
- identifying the appropriate form of validation of the works (testing and monitoring method and frequency of testing during construction) (EN 16907-5).

For fills, 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 fill. It may require improvement of the fill material by various techniques (aeration, humidification, mixing with other materials, use of binders). The possibility to obtain the required final properties of the fill may depend on ground improvement techniques, which are not covered by this European Standard.

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” (EN 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 trials including *in situ* testing (EN 16907-3 provides further details on full-scale trials). 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

Fills are built by recognized earthworks methods in order to meet a prescribed behaviour, in terms of resistance, deformability, permeability and durability. These construction methods include the following:

- a) preparation of the formation / platform ready to receive fill (EN 16907-3),
- b) spreading and then compacting layers of fill material (EN 16907-3 and -4),
- c) placement of coarse granular material such as boulders (EN 16907-3),
- d) hydraulic placement of fill (EN 16907-6 and EN 16907-7).

The expected properties of the fill are defined by the earth-structure design. The earthworks design is the process of determining the appropriate way to construct the earthwork in order to satisfy these properties and the end use requirements of the completed fill, and the development of the technical Specification that defines the requirements to be satisfied during construction, including how to monitor and quality control the construction works. In the cases of c) to d) above, the properties of the completed fill may be obtained by dividing the fill into zones (6.2.2), with different requirements for each zone.

6.2.2 Fill zones

6.2.2.1 General

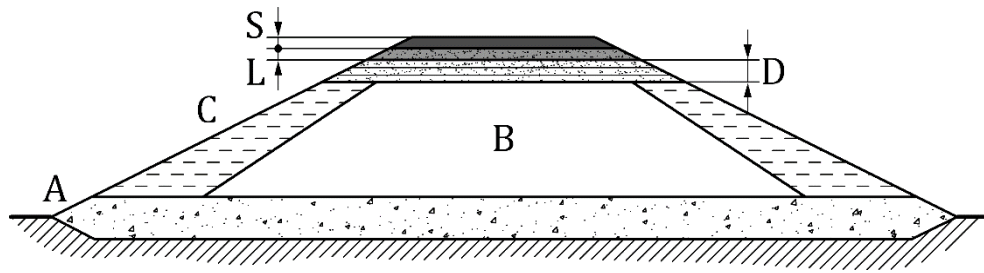
The cross section of fill can be either homogeneous, or divided into different zones, when needed. Each zone shall then be defined in terms of geometry, acceptable material classes, density and other mechanical, physical and chemical properties of the compacted material.

6.2.2.2 Infrastructure fills

The cross-section of infrastructure fills (for highways, railways, waterways, flood defence, dykes or dams) may be divided into zones, which might commonly include the following zones (see Figure 1), although the project design might identify particular requirements that require additional subdivision / zones within the fill:

- **Base (A)**: Fill 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)**: Fill zone located between any base layers and the upper zone (where the embankment is of sufficient height). The core can be protected from water or isolated to limit pollution of the environment.
- **Shoulders (Side zones) (C)**: lateral zones of fills. 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, or another layer with a particular function. It does not include the superstructure layers.

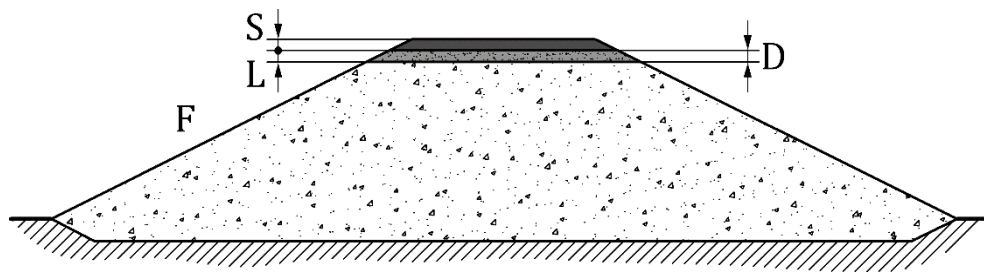
The fill materials in zones A, B, and C may be the same provided the material satisfies the requirements of each zone (Figure 2, example for general case).



Key

- A base
- B core
- C shoulders (side zones)
- D upper zone of multiple layers
- L capping layer (part of upper zone)
- S superstructure (pavement / rail track) (not part of earthworks)

Figure 1 — Zones of infrastructure fill: general case



Key

- D upper zone of a single layer formed by the capping layer
- F fill
- L capping layer (part of upper zone)
- S superstructure (pavement / rail track) (not part of earthworks)

Figure 2 — Zones of a homogeneous infrastructure fill (example)

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 either by the fill materials available on site, or by other locally available fill materials.

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

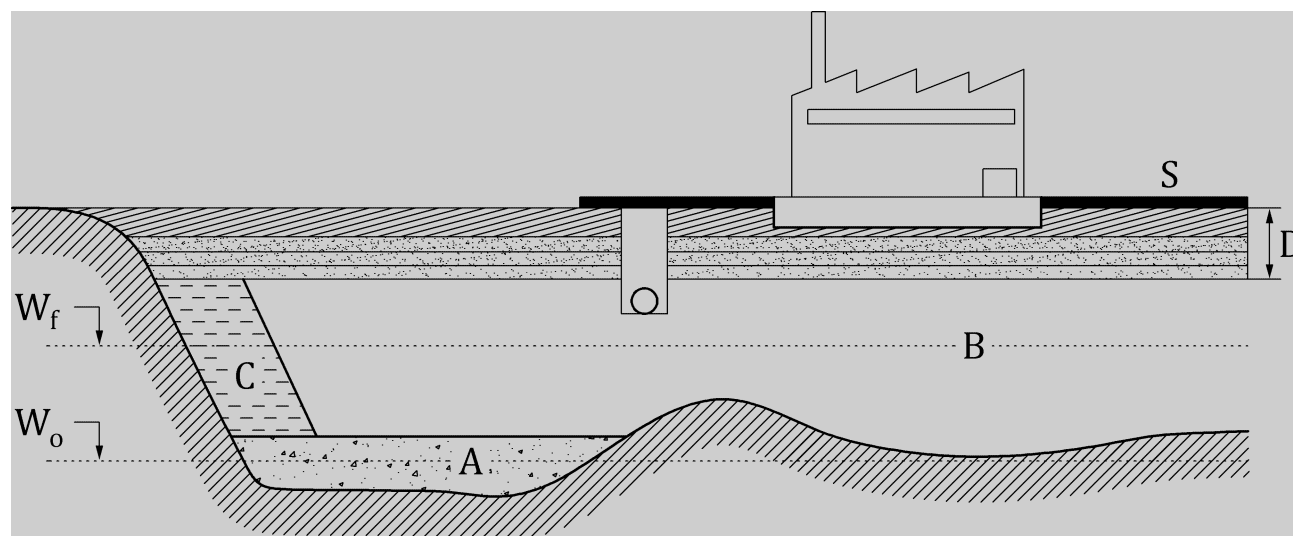
- the potential for settlement below, or changes in volume within, the fill post construction;
- the protection of materials sensitive to water;
- the insulation of polluted materials to avoid leaching of pollutants;

- the separation of materials sensitive to the chemical properties of another layer, e.g. separation of the core fill from foundation layer;
- the effect of the construction traffic (load and vibrations) on the natural ground and fill material properties;
- the effect of the construction procedure on the geometry of the core and side zones.

6.2.2.3 Filling large excavations and natural depressions

Infilling of large excavations or depressions may be divided using the same zones as for infrastructure fills (an example is of filling a large excavation is illustrated at 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 cases where loose uniform graded 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 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.

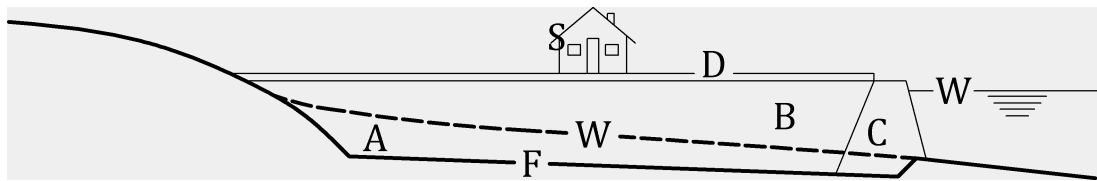
**Key**

- A base (in the example the base layer is utilized to enable fill to be placed in flooded areas of the excavation)
- B core
- C shoulders (side zones)
- D upper zone
- S superstructure
- W₀ water table at the beginning of works
- W_f water table at the end of works

Figure 3 — Example of zones of fill in excavation or depression

6.2.2.4 Land reclamation by dredged hydraulic fill

Land reclamations created by hydraulic placement of dredged material are usually divided into zones within the overall body of the fill (in a similar manner to those described within paragraphs 6.2.2.2 and 6.2.2.3), an example of how this could be achieved for hydraulic fill for land reclamation purposes is illustrated at 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 where necessary to remove compressible deposits. Lateral bund structures or dykes are commonly used to limit the extent of filling, prevent spill of hydraulic fill into the environment and enable construction of steeper slopes. The upper zone may contain a number of transition layers to provide a platform for the superstructure.

**Key**

- A base (soft natural soils are removed by dredging and replaced by hydraulic fill to form the base layer)
- B core (hydraulic fill)
- C bund
- D upper zone
- F formation (the lower limit of the dredged zone)
- N original ground level prior to dredging;
- S superstructure
- W surface of water (lake, river or sea)

Figure 4 — Examples of 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.

6.2.2.5 Buildings and structures on fill

The earthworks design shall include consideration of all aspects that could impact on structures to be formed on or within the fill, including:

- total and differential settlement of shallow foundations;
- negative skin friction on piles or shafts through the fill;
- lateral pressure due to compaction on immediately adjacent structures (such as bridge abutments and retaining walls),
- differential settlement between piled structures and ground bearing elements / utilities,
- stability of the fill under earthquake action and excessive pore-pressure development.

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 the designer shall give careful consideration to: the depth of fill material, permissible fill materials to be utilized, the compactive 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 void content 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 fill, which may appear to 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 compactive effort required are sufficient to ensure that the compacted fill will not suffer unacceptable post construction changes (6.3.3 and 6.3.4).

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. 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 the available materials to be gained from the cuttings or borrow pit excavations 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 borrow 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 (most commonly grading and plasticity see Clause 5.3). The design process of selecting the acceptable range of material state 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, shear strength or deformation modulus (or an earthworks test that relates to these properties). For recycled materials and by-products the characterization must include the content and release behaviour of dangerous substances to evaluate the environmental impact of the application of the material.

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.

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 EN 16907-3, EN 16907-4, EN 16907-5, EN 16907-6 and EN 16907-7, because earthworks design continues throughout execution.

This design process can be considered as an overall system that involves the following three stages of activity (references to parts of the EN 16907 series are related to each item and are shown in brackets):

Fill Design Stage 1 – assessment and characterization of the materials available (see Clause 6.3.2), which includes:

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

Fill Design Stage 2 – assessment of the fill behaviour and the limitations to be placed on use of each fill material (see Clause 6.3.3 to 6.3.5), 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 (EN 16907-2 or this standard, informative annexes on existing practice B to H);
- assessment of the compaction behaviour of the fill materials (EN 16907-1, EN 16907-3, EN 16907-4, EN 16907-6 and EN 16907-7);
- identification of the acceptable water content and density range to satisfy the required earth-structure performance criteria;
- definition of the earthworks technical specifications and requirements for the project.

Fill Design Stage 3 – selection of appropriate construction and control methods for the earthworks construction (see Clause 6.3.6), which includes:

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

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 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 stage of all procedures for earthworks design (see 6.3.1). Identification involves the characterization of the nature of soils and rocks. This will include water content and some of the following intrinsic properties: grain size distribution, carbonates, sulfates, organic matter contents, plasticity and liquidity limits, methylene blue value for soils, Los Angeles coefficient, dynamic fragmentation, friability, degradability, fragmentability, for rocks, and specific tests for other materials. This information is used to classify the materials (EN 16907-2).

6.3.3 Criteria for assessing the compacted fill material

The requirements to be satisfied by the earth-structure are identified 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 fill, and may include some or all of the following:

- criteria relative to the completed fill:
 - minimum value of the vertical deformation modulus;
 - minimum value of the bearing resistance (based on a specified test method);
 - maximum or minimum value of the permeability, when required;
- criteria relative to construction phases:
 - trafficability (for ease of execution);
 - quality of compaction/method of working requirements, for example:
 - the fill material shall not become unstable due to generation of excessive pore water pressure during compaction due to over compaction leading to matting, or
 - change post compaction due to desiccation resulting in separation of layers or cracking;
 - workability (e.g. water content of borrow material compared to the optimum one for compaction)"
- criteria relative to durability:
 - long-term stability of the compacted fill, especially resistance to water content changes (limited collapse, heave and settlement);
 - frost resistance;
 - degradability.

The above criteria shall be transformed into technical specification 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 standardized 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 Proctor 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 (Clause 6.3.7) 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 or degree of compaction, when applicable, to specify the desired state of the fill material after compaction, see Clause 6.3.4 for details.

6.3.4 Compaction behaviour of fill materials

The assessment of the compactability of each available fill material is Stage 2 of the fill design procedure described at Clause 6.3.1. Where ever possible the fill material behaviour shall be tested in the laboratory. Where the material is too coarse for laboratory testing the assessment is made based on experience and the results of full-scale compaction trials (EN 16907-3). The laboratory compaction tests should 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 Proctor and modified Proctor tests, which differ by the applied compaction specific 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 Proctor and modified Proctor laboratory tests on a single soil type (same soil sample in this case) 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.

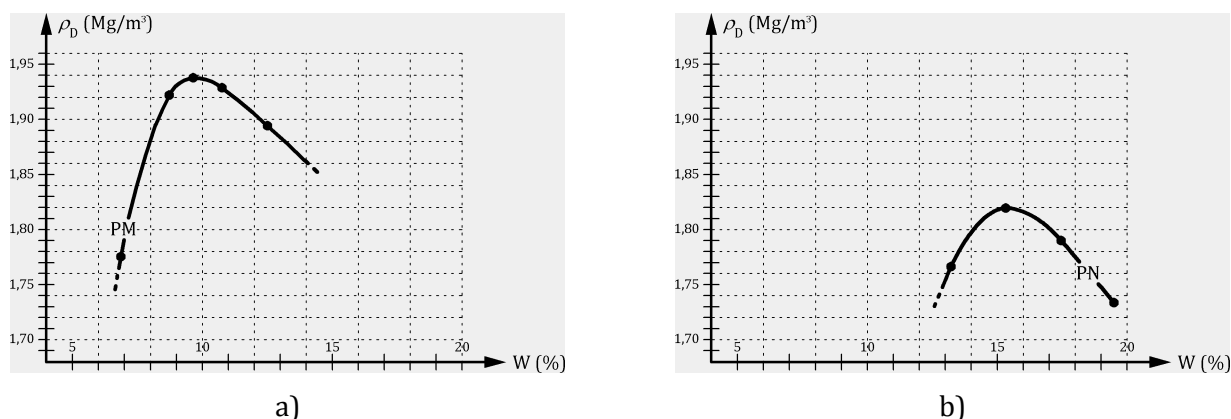


Figure 5 — Examples of (a) modified Proctor (PM) and (b) Proctor (PN) curve test results

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 density of the material particles 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 lower and upper acceptability limits, 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, etc. The factors relevant to the particular soil should be identified, and the potential for post compaction changes assessed by the designer.

A zone (or an interval) of accepted water contents that produce a satisfactory densification should be defined for each fill material (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, relating to water content, see Figure 6a:

- Upper acceptable limit – normally defined based on a required percentage of the maximum dry density.
- 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 pore water pressures due to compaction (e.g. a fill at point A on Figure 6b 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).

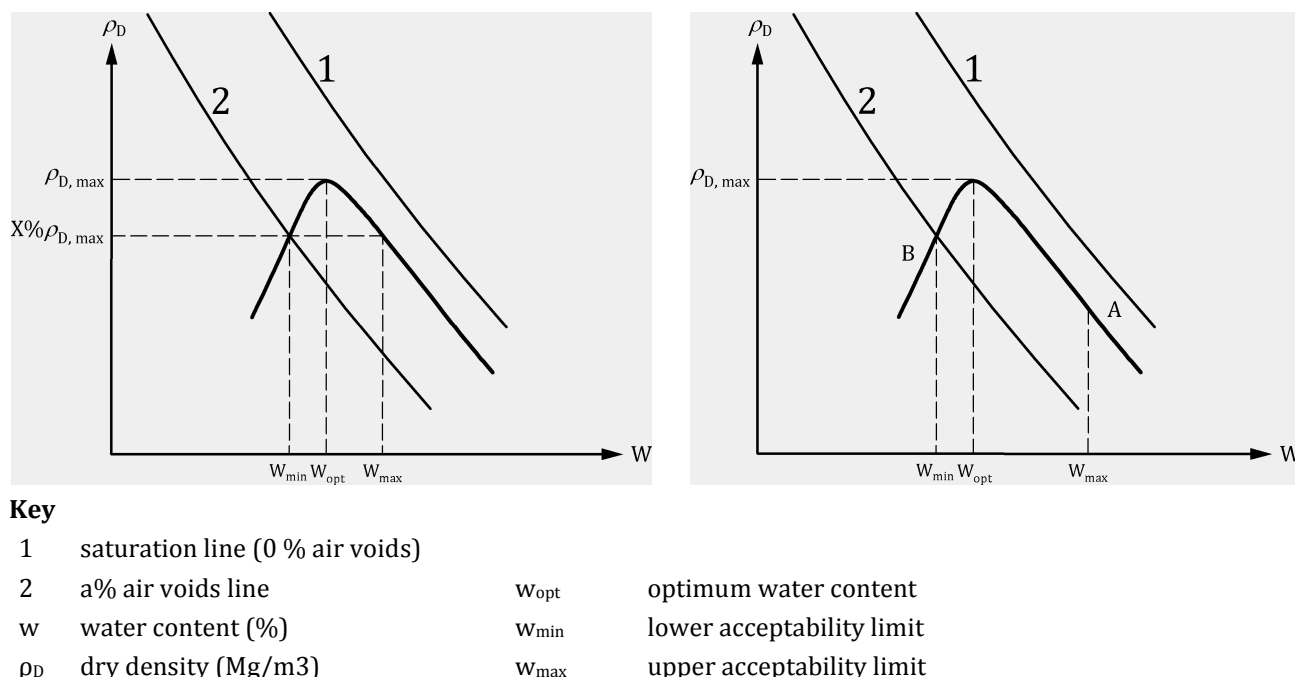


Figure 6 — Examples to illustrate the definition of a water content range based on compaction curve (a) coarse soils and (b) fine soils

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).

Settlement upon inundation with water is a major hazard for buildings and other structures founded on significant thicknesses of fill (cl.6.2.2.5). This risk is very high where fill is placed below the potential long term groundwater level (e.g. infilling a quarry, cl.6.2.2.3), but can occur in various other situations (e.g. around a broken water pipe). Where structures could be adversely affected the earthworks design criteria for placement and compaction of the fill should be set to avoid post construction settlement within the fill. This should include a requirement for the fill below the foundations to be compacted to a low air voids content (for example < 5 % air void content for well graded granular fill). Soil stabilization using binders is a possible option

Specific information on how these issues are addressed for common types of fill material, and similar examples based on saturation lines, are included within EN 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 the various laboratory tests undertaken should be plotted by the earthworks designer on a single graph, or set of graphs with common axis (normally using water content as the x-axis), to review the effect of changes in fill properties 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. This approach also enables the earthworks designer to identify whether the particular fill material is suitable for the required end use. This process completes the laboratory assessment of the potential fill material and enables the development of the earthworks technical specification.

The relationship testing process requires 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 (see 6.3.7). 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. In most cases, the construction method has to be changed to use the existing materials. On some rare occasions, the earth-structure design has to be modified to account for the available materials.

6.3.7 Use of full-scale tests to assess a compaction process for a given fill material

The appropriate compaction procedure to be used for each fill material should be selected at the design stage of the project. Full-scale tests are useful in many cases, and should normally be used for testing fill materials of unknown behaviour or new equipment or expected better compaction procedures.

These tests need to register the following elements:

- the fill material properties and its initial state;
- any modifications applied to this material before compaction;
- the layer thickness;
- the compaction equipment used (principle, weight, speed, vibration);
- the number of compaction passes applied to the material;
- the results (mechanical properties of the compacted fill layer).

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 EN 16907-3 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 reflecting the results of the full-scale tests described above. 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 in comparable earthworks conditions.

6.3.8 Design of fill cross-section

The design of the cross-section is part of the earth-structure project, see Clause 6.2.2 and Annex A for examples. 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

6.4 Details of specific parts, materials and earth structures

6.4.1 Introduction

Special design and construction requirements apply to specific parts of earth structures, to the use of specific materials and to specific boundary conditions of the earth-structure, 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 intended functions of a capping layer necessitate 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 fill materials which are sensitive to freeze and thaw or to frost heave;
- 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 geosynthetic, 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 cutting, (see Annex A for an example and appropriate terminology). The profile continues along the infrastructure, roughly showing the intersection between fill and natural ground, until a full cutting 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 cutting-fill contact should be considered.

6.4.3.3 Transition from embankment to cutting

Transitions from embankments to cuttings are special earth-structures which should be designed to avoid sudden changes in stiffness and frost heave from the bottom of the cutting to the top of the embankment. They shall be built as smooth as possible, both transversely and longitudinally

Transitions in which the succession is downslope, from cutting to embankment, shall be designed in order to avoid the entrance of run-off water into the top of the embankment through its upper layers due to its direct contact with the bottom of the cutting, 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. Part of them are expected from the earth-structure design.

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 stiffness of the structure abutment (concrete, reinforced earth, gabions).

The following aspects should be considered, while accounting for the end use of the earth-structure:

- 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 EN 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;
- Geogrids can be used to reduce differential settlements, and in some situations can reduce lateral earth pressures;
- 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 transitions or structures

Where existing fill is to be extended or increased (transversally), this should be prepared using berms or other relevant measures in order to achieve a suitable junction with the new fill. These operations shall be indicated in the earth-structure project.

For specific purposes, such as protection against floods and erosion, building steeper slopes, one or both side zones of a fill may be replaced by special structures. 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 fill

As a first approach, the problem should be focused under a close point of view to that of transition from fill to structure (see 6.4.3.4), by means of specific design from the top and sides of structure:

- vertically: from the top of the undercrossing structure to the superstructure;
- horizontally: from the edges of the undercrossing structure to both sides.

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. For equal dimensions of the undercrossing structure, the deeper the undercrossing is, the lesser is its influence on the superstructure. The following distinction can be made:

- deep undercrossing structures: If transition in stiffness, by means of one or different layers, provides homogeneous bearing conditions for the superstructure above;
- shallow undercrossing structures: If changes in stiffness are not able to provide homogeneous bearing conditions for the superstructure above.

6.4.4 Fills on slopes

This type of section takes place when the cross section of the earth-structure is made of a fill 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 fill 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 fill and possibly soil replacement by granular material under the toe are most important (see Figure 10).

6.4.5 Specific materials

The design of fills 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 artificial 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 should be taken into account.

The general framework for the specific materials used for construction of earth-structures shall give consideration to the following general aspects:

- health and safety during construction;
- 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 materials, which require specific design when used for earth-structures, but not about every specific waste, by-product, or artificial material.

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

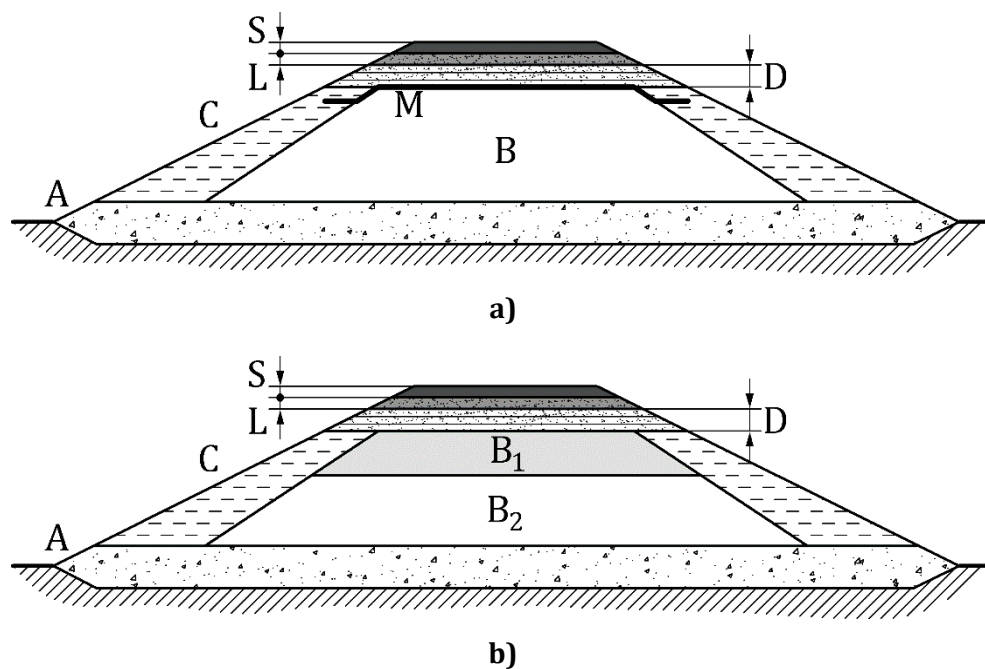
- chalk (see EN 16907-3:2018, Annex B, Clause B.6),
- arid soils (see EN 16907-3:2018, Annex B, Clause B.7),
- tropical residual soils (see EN 16907-3:2018, Annex B, Clause B.8),
- soils containing soluble salts (see EN 16907-3:2018, Annex B, Clause B.9),
- active clays (see EN 16907-3:2018, Annex B, Clause B.10)
- permafrost (see EN 16907-3:2018, Annex B, Clause B.11).

Generally, these are:

- materials with particular constituents;
- very dry or very wet materials;
- very clayey materials;
- uniformly graded fill 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 fills the core of which is made of marginal materials are shown in Figure 7.



Key

- | | |
|----|---|
| A | foundation |
| B | core (marginal material sensitive to water action) |
| B1 | upper part of core made of low permeability material (usually clayey soil) isolating B2 from upper infiltration and providing weight if B2 is a swelling soil |
| B2 | marginal material (sensitive to water action) |
| C | impervious side zone (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 fill

6.4.6 High fills

The risk of settlement after construction is increasing with the height of fill. High fills (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 fills, and

when used this should only be under strict design prescriptions. High fills shall have their stability checked by a soil mechanics type of approach. Deformability of the fill foundation soil shall be checked in addition.

The self-settlement of high fills, 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.

For high fills the use of end product specification is recommended. In addition, it may be necessary to include a monitored hold period once the earth-structure reaches full height and prior to completion of any sensitive elements of the infrastructure upon the earthworks.

Unexpected long term settlements affect longitudinal profile as well as cross section and can disturb drainage. If the drainage chain is broken, additional water is injected within the fill, thus often contributing to more settlements.

6.4.7 Fills on soft soils or areas prone to flooding

Design of fills on soft soils shall be done in accordance with EN 1997-1. Specific techniques (soil improvement or substitution, stone columns, etc.) could be needed to provide adequate resistance to subsoil prior to earthworks construction.

When selecting fill materials to form embankments to be placed on soft soils or areas prone to flooding, 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 drier than the optimum water content) should not be utilized below the predicted flood water level;
- the necessity for a granular starter layer to provide a drainage layer and help form 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 fill, which may necessitate incorporation of geosynthetic reinforcement, and a geotextile separator may be necessary at the top and / or base of the starter layer if it is constructed of 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 fill can dissipate at a rate that ensures the stability of the fill during construction. Several phases of fill construction will eventually be decided (this is part of the geotechnical design of the earth-structure).

6.4.8 Fills built above cavities

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

- no specific action is needed and the fill 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 for the presence of the fill;
- other specific designs shall be adopted (for example: light fills, piled structures, geogrid reinforced mattresses).

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. When necessary, stability calculations according to EN 1997 shall be performed considering the potential changes in soil properties that may take place post construction (similar to all earthwork slopes).

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 EN 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 and rock used in fills. 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 EN 16907-3). Terminology for elements of cuttings are shown in Annex A.

Many of the aspects related to the design of fills also apply to the design of cuttings (e.g. stability of existing slopes, cavities, drainage) (see Clause 6.4 of this standard). These requirements are not repeated here.

7.2 Materials involved

Apart from geological classifications, materials within the proposed cuttings can be classified according to the construction procedures necessary to achieve the excavation. A first approach to this topic should be (see EN 16907-3):

- strong to intermediate rocks (blasting, pre-splitting);
- intermediate to weak rocks (ripping, excavation);
- soil (excavation by conventional plant alone).

The potential excavatability of cuttings can be preliminarily estimated by means of geotechnical and geophysical investigation and *in situ* testing. 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 to be used for building fills.

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

7.3 Geometry

The earthworks designer shall ensure that the stability of cuttings slopes as assessed in accordance with EN 1997 is not adversely affected by the construction method and the actual ground conditions encountered. The stability of slopes during construction may be influenced by:

- height and slope angle of the cutting at any stage of the construction;
- materials involved (see 7.2);
- geological structure: overall framework of the cutting, and detailed behaviour of each formation;
- drainage conditions (see 7.4);
- temporary stockpiles of fill materials;
- temporary excavations;
- land available for construction;
- environmental restrictions.

Each geological formation has its own specific stability patterns, highly affected by drainage conditions. Thus the slopes in a cutting can be either constant or variable, particularly for slope gradients, overall height, and drainage. The design can also include one or various berms located at intermediate heights all over the cutting or in specific places.

Cuts 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 formation (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. Stability shall be assessed in accordance with EN 1997-1. Also considerations about geometry included in 7.3 shall be taken into account.

NOTE The weathering of formations can influence their long term behaviour in terms of excavatability, slope stability and other relevant properties.

7.6 Relevant properties of the cutting base (subgrade)

The base of the cutting is the platform “formation” on which superstructure will be placed. The required properties of the earthwork material that form the base of the cutting will normally be 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, swelling or soluble soils).

The earthworks construction activities shall be planned 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 the appropriate form of earthworks drainage installed either during or immediately after a cutting is extended to a particular level. A protection layer may be used to prevent damage to the cutting base (e.g. a sacrificial layer of fill or soil).

The earthworks designer shall identify ground conditions that present a clear risk to the construction within cuttings (e.g. high pore water 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 fills require special consideration in terms of the above issues because drainage conditions at these locations can be particularly difficult (see 6.4.3.3. and 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 EN 16907-6, but their design has many common features with that of fills 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 EN 16907-6.

The required properties of the completed fill can either be obtained without specific action, when the dredged materials have favourable geotechnical properties and technical 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 wastes

EN 16907-7 relates to the hydraulic placement of soils and mineral wastes derived principally 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, EN 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 EN 16907-7 therefore covers the widest range of engineering applications. The principal elements are not only the placement, stabilization, reclamation and rehabilitation of hydraulic fills made of processed soils and mineral wastes but also 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 EN 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, the standard 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 m² 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. EN 16907-7 provides a framework for the design and construction of the storage facility to meet requisite regulatory standards and to comply with good practice.

10 Earthworks Drainage

10.1 Drainage for collecting water

Temporary and permanent drainage is a major component of earthworks, for excavations, cuttings and fills. It forms an important component of the earthworks solution, influencing various earthworks issues such as the stability of slopes, and the performance of: fill materials during and after construction, the base of cuttings, and any overlying infrastructure.

This standard relates to the successful construction of earthworks, it addresses temporary drainage during construction. However, it is often difficult to clearly delineate temporary from permanent drainage. Many of the earthwork drainage issues described are just as applicable to the operation / performance of the earth structure, and in some cases the permanent drainage of one section of earthwork forms part of the temporary drainage to manage water during construction. In this situation the earthworks designer and construction team shall ensure that soil within the water does not block the drains or adversely affect long term performance. Furthermore, the earthworks construction provides an opportunity to check the adequacy of the proposed permanent drainage.

Two main types of drainage systems can be considered:

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