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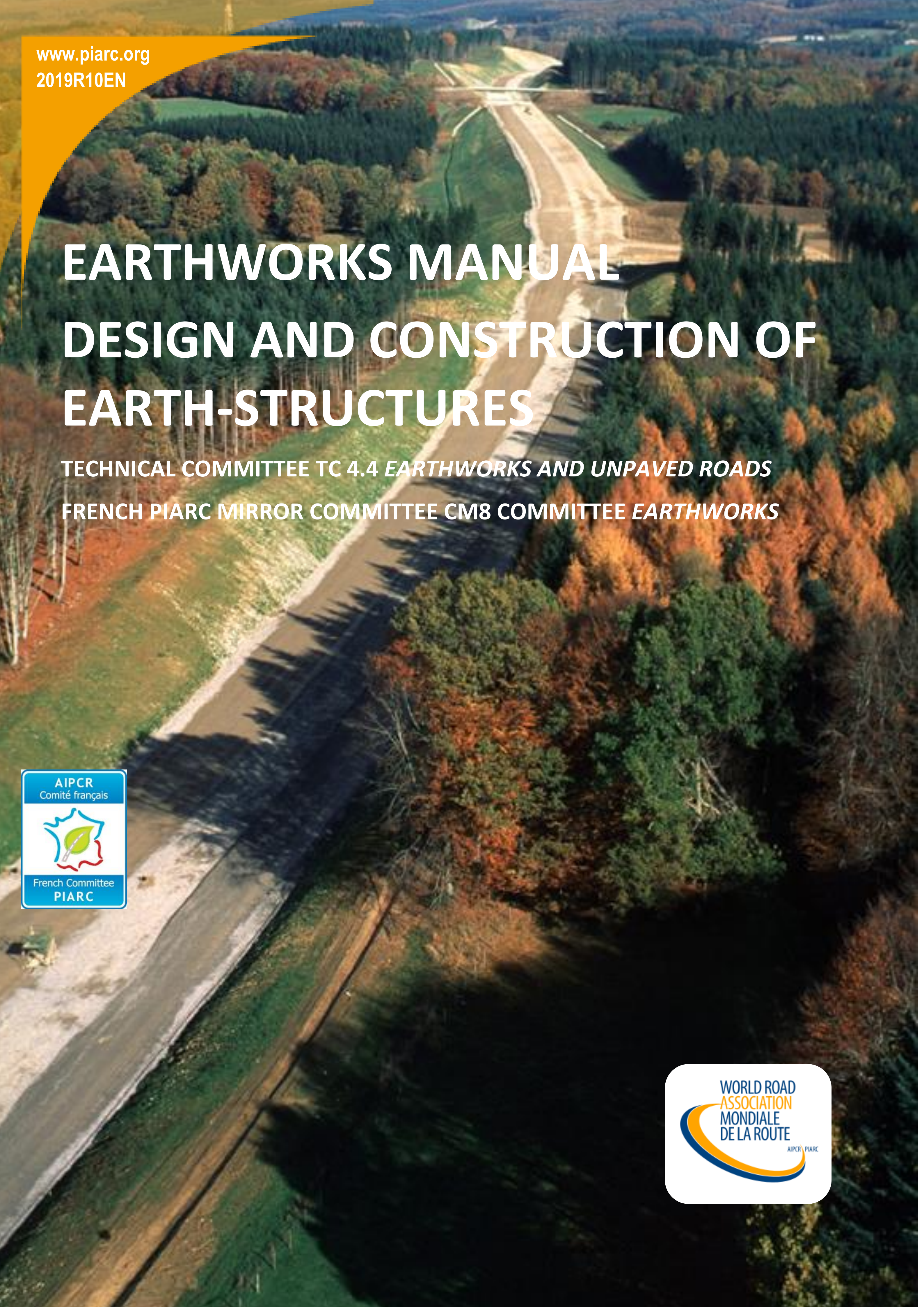
2019R10EN

EARTHWORKS MANUAL

DESIGN AND CONSTRUCTION OF EARTH-STRUCTURES

TECHNICAL COMMITTEE TC 4.4 *EARTHWORKS AND UNPAVED ROADS*

FRENCH PIARC MIRROR COMMITTEE CM8 COMMITTEE *EARTHWORKS*



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STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2016– 2019and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

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World Road Association (PIARC)
Arche Sud 5° niveau
92055 La Défense cedex, France

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AUTHORS/ACKNOWLEDGEMENTS

The Earthworks Manual was developed within the framework of the issues defined in the PIARC 2011-2015 session for Technical Committee TC.4.4 "Earthworks and Unpaved Roads".

The members of TC 4.4 contributed to the preparation of this report:

GARNICA Paul Mexico	***President***
DUBREUCQ Thierry France	***Francophone Secretary***
PERUCHO Aurea Spain	***Spanish-speaking Secretary***
BOSCO Andrew Australia	***English-speaking Secretary***

PETERSON Simon South Africa

HEYER Dirk Germany

THEYS Frank Belgium

OLODO David Benin

TOLLO François Benin

MBOLE MBOLE Benoît Parfail Cameroon

MOON-SEOK Nam South Korea

AIME Claude France

BERNHARD Stephan France

PHILIPPEAU Jean-Marc France

RAOUL Guy France

MITTIGA Enrico Italy

RAKOTOBE Andriafenomanana Madagascar

MOHAMAD Ashaari Bin Malaysia

DIALLO Cheick Oumar Mali

BENDIDI Hind Morocco

GALADIMA Moustapha Niger

HERLE Vitezlav Czech Republic

OLTEANU Andrei Andrei Romania

The preparation of the Manual was entrusted by President Paul GARNICA to a Working Group led by Guy RAOUL assisted by Claude AIME and Franck THEYS.

During the 2012-2015 Session, the following elements were presented and validated by TC 4.4:

- *The summary*
- *The title and structure of the entire Manual with complementary components (Specific Technical Developments), as presented below.*
- *Part 1 General Considerations*
- *Part 2/E Environmental Aspects*
- *The "Controls" part of 2/D Execution of earthworks*
- *The presentation of the Manual at the PIARC Closing Congress in SEOUL (Presentation by Guy RAOUL)*

Structure of the Earthworks Manual

Manual Earthworks / Design and construction of earth structures (road infrastructure)

- ***Part 1 General Considerations***
- ***Part 2 Additional Components / Specific Technical Developments***
- *2/A Materials*
- *2/B The treatment of materials*
- *2/C The earthworks project*
- *2/D Excavation work*
- *2/E Environmental aspects*
- *2/F Earthworks in the construction of unpaved roads*
- *2/G Innovative methods and techniques*

Parts 2/F and 2/G will be complemented by further contributions expected from PIARC member countries

The structure of the Manual having been validated, the elaboration of Part 2 was continued in 2016 and 2017 on the basis of the elements of the 2012-2015 session.

In this phase, in relation with President Paul GARNICA, Guy RAOUL relied, to complete and validate the remaining Parties, on the technical expertise of the members of Mirror Committee N°8 "Earthworks" of PIARC French Committee:

- *2/A Materials*
- *2/B The treatment of materials,*
- *2/C The earthworks project*
- *2/D Excavation work*

PIARC Contribution French Committee

The CM 8 Technical Committee, which had followed the work of the Earthworks Manual during the 2012-2015 Session, was able to provide this technical expertise for the Parties to be completed in subsequent years.

Members of the PIARC CF Committee "Earthworks"

RAOUL Guy (SPTF)	*President*
AIME Claude (SPTF)	*Secretary Session 2012-2015*
BERCHE Véronique (CEREMA)	*Secretary Session 2016-2019*

IFSTTAR

DUBREUCQ Thierry

BOUSSAFIR Yasmina

CEREMA

PRETESEILLE Mathieu

HERVE Sébastien

MATYNIA Anthony

MATHON David.

Technical Commission of the French Professional Association of Earthworks contractors

VARILLON Jérôme

CHARDARD Patrice

LAVALLEE Emmanuel

Daniel GANDILLE

French Professional Association of Engineering and Consulting Companies (SYNTEC)

egis

BERNHARD Stephan

MOLLIER Thierry

LAPPE Isabelle

Additional SPTF contribution

Having provided additional technical expertise to the development of this Manual:

DESSERT Jean-Marc

GAVOIS Ludovic

ROSSI Pierre

Important technical reference

An important reference for the Manual was to have recent technical information provided as part of the European standardisation process conducted by the CEN/TC 396 Technical Committee "EARTHWORKS" (Presentation in Annex 1.1)

The whole Manual was written in French by Guy RAOUL (France).
The English translation of PART 1 was initiated by Franck THEYS (Belgium).
The Spanish translation of PART 1 was realized by Paul GARNICA (Mexico).
Its finalisation is ensured by PIARC with the support of the members mentioned above.

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SUMMARY

2019R10EN

EARTHWORKS MANUAL

The technical specificity of Earthworks corresponds to the management of many parameters and constraints that have an influence on the progress of the design and construction operations. In particular, the construction of earthworks is confronted with geotechnical and climatic hazards.

General considerations on the content of the Manual

The proposed Earthworks Manual is a collection of rules of the art, good practices,... to enlighten and sensitize readers on Earthworks management, at the design stage of earthworks, the project and the execution of earthworks.

The Manual takes into account the different PIARC technical reports produced in previous sessions by integrating them into the extended data of the current session.

The earthworks construction process produces earth-structures: cuts, fills or embankments, pavement support structures meeting specifications for stability, deformation, load-bearing capacity, hydraulic or other.

The quality of the works is required, in particular:

- To ensure the support of pavement structures in accordance with the planned design
- To ensure the durability of earthworks and thus reduce the importance and frequency of maintenance work

The economic and environmental aspects, which are crucial in the construction of road infrastructure, as well as concepts on adaptation to climate change are highlighted.

Design and studies

Geotechnical studies are of major importance to the success of the project, particularly for the following issues:

- material identification
- optimal reuse of site materials
- the stability of the structures
- the design of structures

The required quality of earthworks needs recommendations: technical guides, normative systems and standards, technical specifications, feedback from site experiences, test sites, etc. The Manual includes comparisons between the different approaches practiced in various countries around the world, particularly presenting all of the recent European standards dedicated to earthworks (currently under investigation by CEN).

Execution and controls

The Manual also presents the basic concepts on the project and the execution of earthworks:

- methods and techniques
- material adequacy
- various types of controls: material identification, implementation, binders, equipment.

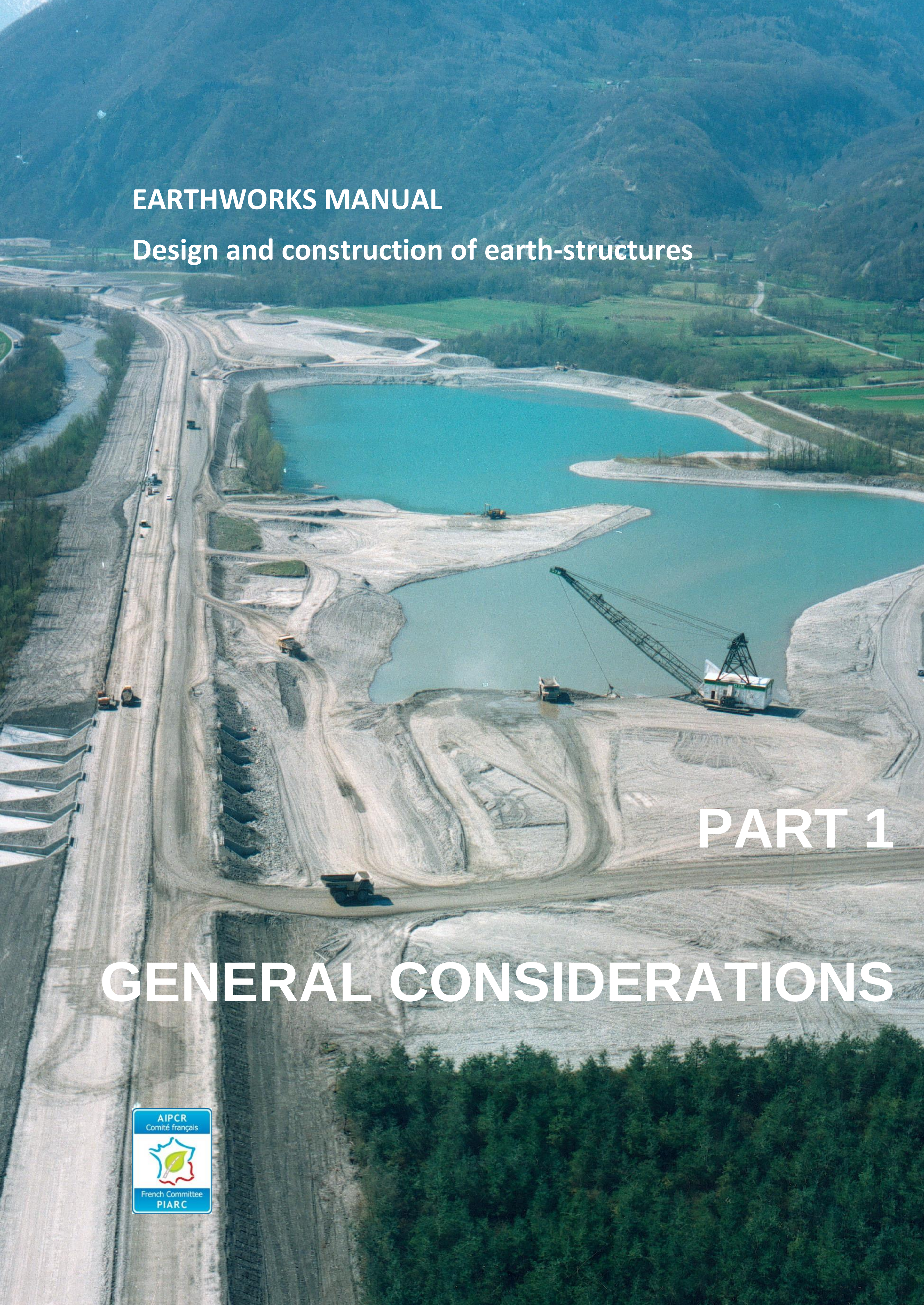
An important part is devoted to the treatment of materials, a technique still under development.

Environmental aspects

A specific chapter is devoted to environmental aspects and proposals for actions to contribute to sustainable development in the field of earthworks.

EARTHWORKS MANUAL

Design and construction of earth-structures



PART 1

GENERAL CONSIDERATIONS

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1. INTRODUCTION

Part 1 is a condensed document that explains the content of the Manual on all the elements to be known about the Earthworks process and the construction of earth-structures
These elements are developed in Part 2 cited in the Preamble.

The Manual cites the sources of the technical references used as a basis for its development. The references are those of PIARC member countries.

1.1. PURPOSE OF THE MANUAL

It is a collection of rules of the art, good practices, technical standards... to enlighten and sensitize readers on Earthworks management, at the various stages of the design of earthworks, the project and the execution of earthworks.
The Manual is a stand-alone technical document that takes into account economic and environmental aspects as well as concepts on adaptation to climate change.

The Manual brings together the technical knowledge shared in the field of earthworks for 25 years at PIARC

1.2. DEFINITION OF EARTHWORKS

The term earthworks is used to describe different concepts.

- ➢ Significant economic activity in the field of infrastructure and development

- ➢ Set of operations / execution process, which includes:
  - extraction, loading, transport
  - transformation and improvement
  - the implementation, stabilization and compaction of natural materials (soil and rock), secondary or recycled materials in order to obtain stable and durable cuts and fills.

The work may be carried out underwater.

- ➢ Construction of earth-structures

The construction process of the Earthworks produces earth structures: cuts, fills or embankments, capping layers, meeting stability, deformation, hydraulic or other specifications.

Technical objectives: stability, absence of damaging settlement, ability to withstand natural stresses (water, frost, weather conditions, deformation of the foundation,...) and the constraints imposed by civil engineering structures.

European standard reference "Earthworks" Part 1 / General principles and rules (EN 16907-1 § 4)

Principles of earthworks design and execution

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.

1.3. References

1.3.1. Technical documents "PIARC"

- PIARC" technical reports concerning earthworks, drainage, climatic conditions, etc.
- international seminars with which PIARC is associated

1.3.2. External technical documents

References from different countries around the world may be used to complete and enrich the content of the Manual

- technical guides
- normative systems and standards
- technical specifications
- specialized papers
- research, theses,...
- site feed back, test sites,...

The new reference of European countries should be highlighted. The interest lies in recent joint work carried out on the entire Earthworks activity.
The reference corresponds to the European standardisation project concerning the "Earthworks" standard, currently under investigation by CEN and published in 2018.
(See Annex 1/1 European Standard "Earthworks")

2. GENERAL CONSIDERATIONS

2.1. SPECIFICITIES OF EARTHWORKS

The general considerations are technical, economic, environmental and strategic and characterize the specificity of earthworks.

2.1.1. Technical specificity of the earthworks

The execution of earthworks is primarily subject to geotechnical and climatic hazards. Many parameters and constraints influence the flow of operations.

- variety and heterogeneity of materials (soils) encountered
- extraction and implementation difficulties: loose soils, rocky soils...
- problems linked to materials reuse (treatment, making up...)
- trafficability (flow of machiness)
- climatic conditions,
- water control: drainage, surface water...
- interfaces with other activities (pavements, civil engineering, etc.)
- …

2.2. ECONOMIC ASPECTS

Below we give some indications on the economic importance of earthworks in the construction of road infrastructure, as well as some representative figures.

2.2.1. Earthworks activity

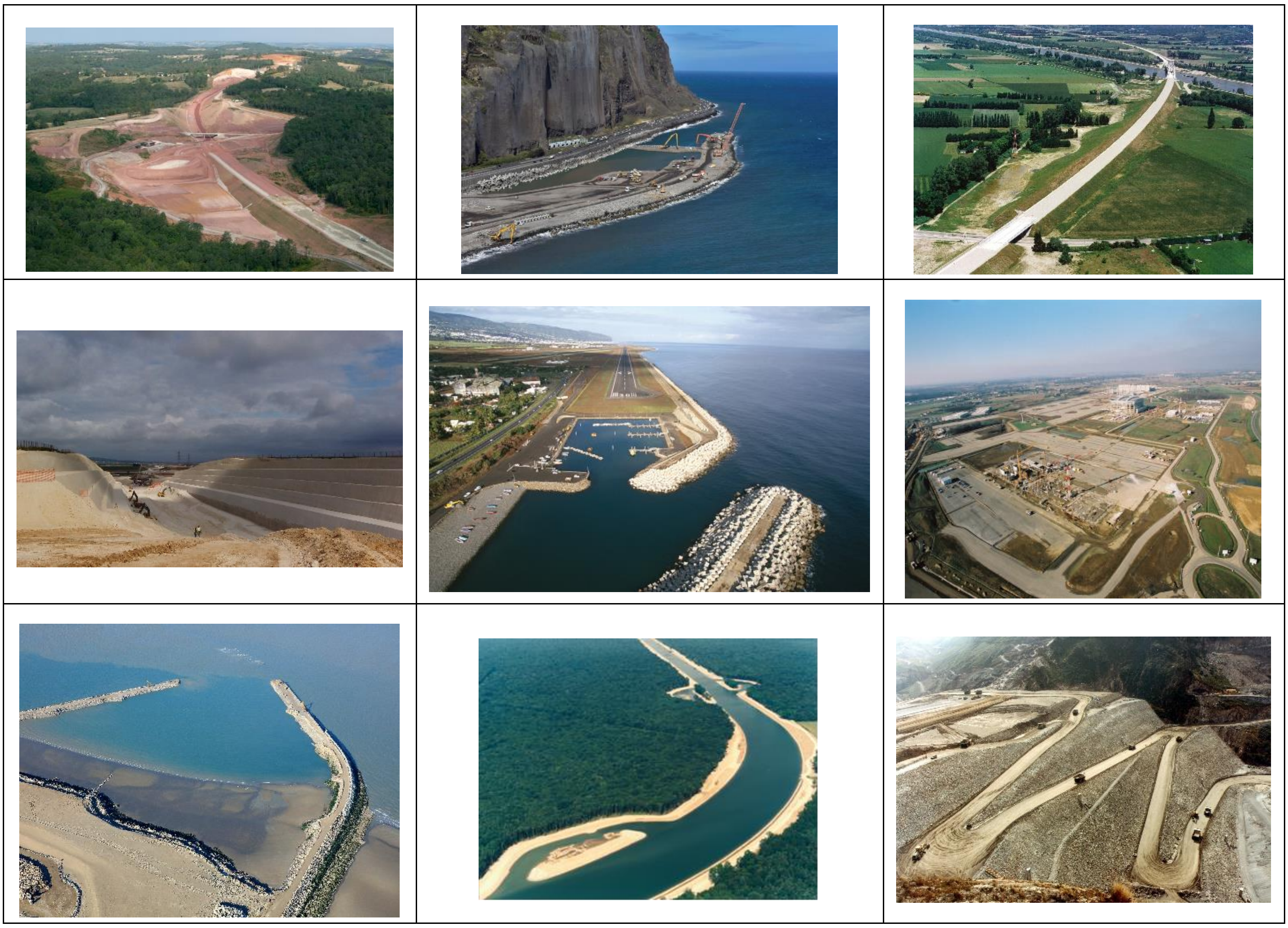
The Earthworks activity represents 15 to 20% of the overall Civil Engineering activity.

In the field of infrastructure and development, the economic impact of earthworks is very significant.

Field of major earthworks

The Earthworks activity includes the construction of earthworks for all types of transport infrastructure and associated facilities:

- ❖ Road and motorway infrastructure
- ❖ Railway infrastructure including high-speed lines
- ❖ Harbor and airport facilities
- ❖ Logistics and multimodal platforms
- ❖ Waterways including large canals
- ❖ Hydraulic and hydroelectric facilities: embanknt dams, dikes,...



Set of pictures 1

The cost of earthworks has a wide range of variation depending on the nature of the road project. It depends in particular on the topographical configuration of the project, the nature of the materials...
In the average configuration, for example, the volume of earthworks / linear of highway and motorway infrastructures (2X2 lanes) may thus vary from :

- 50,000 m3 to 250,000 m3 /km of materials to be moved
- Up to 300,000 to 400,000 m3 in "mountainous" sites

The Earthworks activity is highly mechanized. On average, the material cost (excluding operator) represents one third of the total cost of earthworks.
The depreciation portion is high due to the investments to be made. For example, the purchase of machinery constituting the most commonly used "earthworks teams" for major roadworks varies from about 150,000 to 1,000,000 Euros per machine.

Breakdown of equipment expenses for one hour of equipment operation

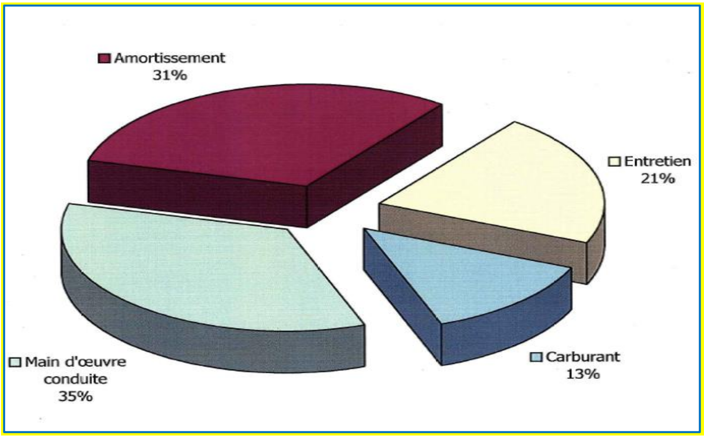


Figure 1

Fuel consumption

Average ratio observed: 1 litre of Domestic Oil Fuel per m3 excavated

2.2.2. Economic impact of the Earthworks

The following graph shows the average impact of earthworks on the overall cost of motorway projects and High Speed Lane projects.

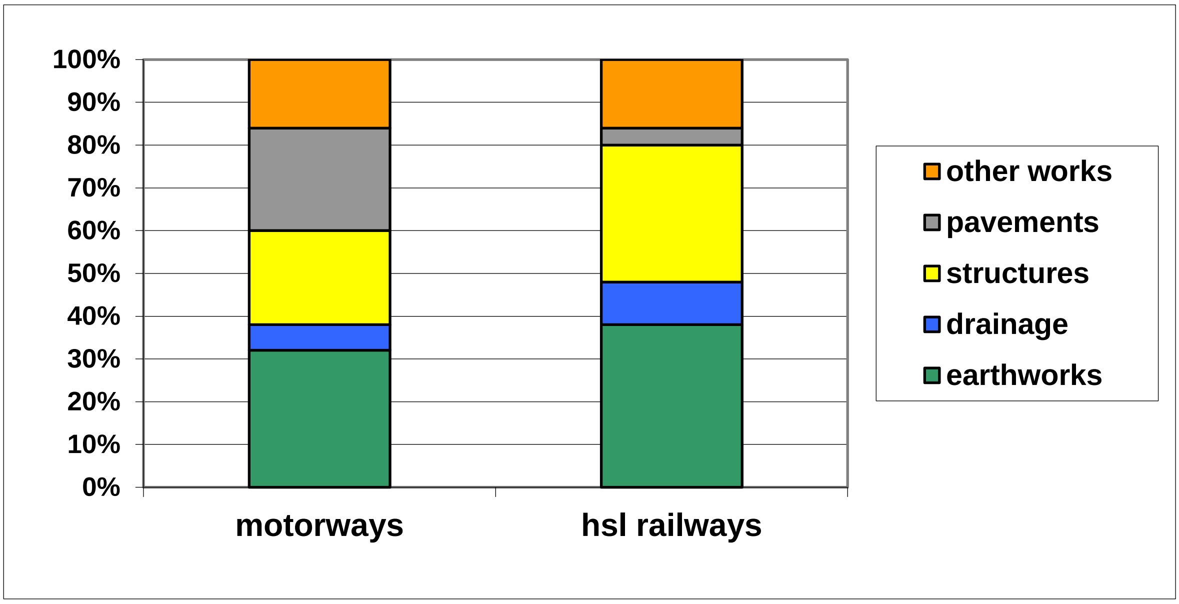


Figure 2

The potential for improving project costs, induced by earthworks techniques, is therefore high.

Cost optimization is sought at the design stage of the road infrastructure alignment and then at the design stage of the earthworks themselves.

This optimization is due in particular to innovative solutions for the use of site materials, the adequacy of the equipment used and the optimization of the work program.

❖ Adequacy of equipment

Main earthmoving teams / Haulage distances

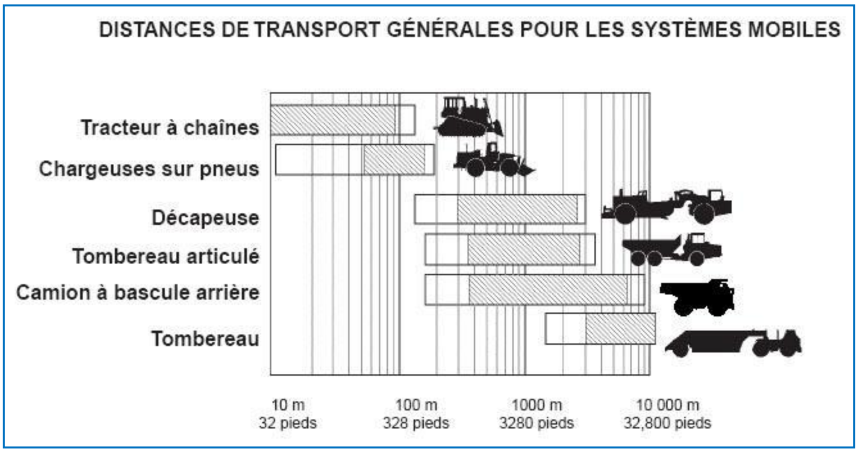


Figure 3

Cost optimization primarily concerns the earthworks part (particularly backfill). It may also concern the engineering structures and hydraulic structures part (adjacent embankments, access roads, etc.), possibly the retaining walls (reinforced earth, reinforced earth, etc.), the tunnel parts (reuse of excavated material, access, tunnel heads, etc.).

❖ Complex / Earthworks upper part / Capping layer / Pavement

Optimization is also sought at the pavement platform level (capping layer) in the overall pavement structure (pavement structure design).

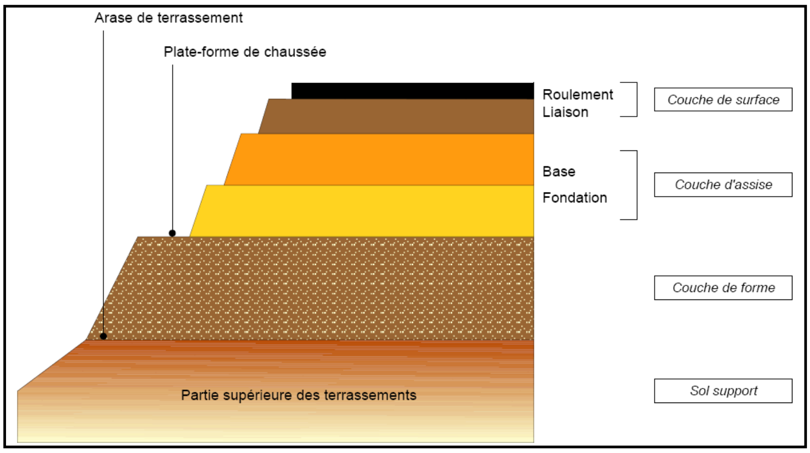


Figure 4 - Structural layers of the pavement

Cost reduction is particularly important when this use replaces external borrowing solutions or even quarry products.

The lever arm is all the more important as it is applied to the lower layers of the pavement structure, particularly in the earthworks phase.

2.3. Environmental aspects

2.3.1. Introduction

Any development project has an impact on the three pillars of sustainable development:: the environment, the economy and the society.

Earthworks is the stage where the impact will be greatest and where development proposals to deal with these impacts can be implemented (Avoid, compensate, reduce these impacts,...)
Impact assessment is a complex exercise that requires having:
- means of analysing the existing situation before the development project,
- analysis of the project and the supposed impacts,
- analysis of so-called compensatory solutions.

There is no international consensus on these three points. There may even be divergence in analysis depending on the scales of issue analysis.

The points of vigilance in terms of sustainable development to be applied to earthworks are:
- the fight against climate change and the protection of the atmosphere,
- the preservation of biodiversity, the protection of environments and resources,
- social cohesion and solidarity between territories and between generations,
- development dynamics trespecting sustainable production and consumption patterns.

For each point, elements of project analysis should be provided.

2.3.2. Impacts to consider

The earthworks project must take into consideration the natural elements to be protected and preserved:
- habitat, heritage, agriculture, forestry, landscape
- underground resources
- water resources (wellfield)
- fauna, flora, water, soil
- archaeology

as well as the sites crossed presenting environmental risks

- polluted sites
- waste products
- classified facilities (technological risk)
- ...

2.3.3. Contribution to sustainable development

In addition to taking into account the elements mentioned above, the main contribution to sustainable development is the optimization of the reuse of the site's materials, which reduces the impact of transport:
- reduction in the impact of inputs and transport outside the site (trucks traffic)
- at the same time preservation of natural resources outside the site

Other contributions are to be highlighted:
- recovery of industrial by-products: fly ash, blast furnace slag, Municipal incinerator bottom ash1 (excluding fly ash) (MIBA) [1], sludge, etc.
- specific techniques reducing energy: aeration,..

Further improvements are to be sought:

- reduction of energy consumption (through equipment improvements...)
- reduction of water consumption, especially on site tracks and in the use of materials (use of sprinkler-undercutters, dust fixing products, etc.)

These examples of Earthworks' contributions to sustainable development are cited in the European standard "Earthworks - 1/Principles and general rules", which recommends that earthworks be designed in a spirit of sustainability.

[1] Including the treatment of the household waste

2.3.4. Evolution of the consideration of environmental protection in the world

❖ Environmental protection / Global context

Reference PIARC Technical Report 2003 "Limits of use of natural soils, specifications and controls in earthworks"

There is a more and more increasing request in every country to enhance the protection of environment and of life setting to the detriment of our traditional, technical constraints (cf.: conclusions of PIARC Congress 1999 in Kuala-Lumpur and especially the C12 ones in magazine Roads N°305 - January 2000 – pp. 50 to 53). One among the consequences of this request leads to look for earthmovings very short and, when possible, in the right of way of the road. So it is more and more unacceptable from an engineer he classes a doubtful soil of a cut as unsuitable to fill an embankment, sometimes a subgrade, while it could previously be laid in a definitive depository and possibly compensated by a borrow pit of attractive soils, sometimes far enough from the work place.

❖ Need for adaptation to climate change

In the field of earthworks, this objective is becoming a priority. The technical standards applicable in the countries concerned must be reviewed.

Recent global reference
2015 Paris Climate Conference

The 2015 Paris Climate Conference was held from 30 November to 12 December 2015 at Le Bourget in France. It was both the 21st Conference of the Parties (hence the name COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) and the 11th Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol (CMP11). Each year, the participants of this conference meet to decide on the measures to be implemented in order to limit global warming.
This international summit brought together 195 countries. An international climate agreement, applicable to all countries, has been validated by all participating countries, setting a target of limiting global warming to between 1.5°C and 2°C by 2100.

2.4. EARTHWORKS STRATEGY

The Earthworks strategy is essentially based ontwo approaches:

- ❖ Optimization of earthmoving:
- reuse of site materials according to their destination, possibly transformed (aeration, binder treatment, processing, etc.)
- haulage distances
- traffic conditions (site tracks)
- ……
- ❖ Optimization of time through work planning:
- appropriate means (equipment, personnel)
- technical solutions and work execution periods according to the sensitivity of the materials (water, rain and snow, temperatures, freezing)
- ...

These studies are based primarily on the following data:

- ❖ geological and geotechnical data
- data used from the design to the implementation stage
- ❖ meteorology / weather conditions
- exploitation of meteorological station data
- estimate of the number of foreseeable days of bad weather (rain, frost)
- objectives: optimization of lead times and material reuse

- ❖ Adaptation to climate change

First steps to consider:
Taking into account the effects of climate change requires all stakeholders in an earthworks site (administration, contracting authority, Engineer, or contractor) to take measures to reduce water consumption while the water content of the materials to be reused decreases. Technologies must therefore adapt to save this resource.

It is the same forearth-structures already in operation, some of whose constituting materials may change their water state and thus weaken the structure that was not designed with these new assumptions. A follow-up of the structure, or even its reinforcement, is then necessary.

2.5. RISK AND HAZARD MANAGEMENT

Our approach in this area is purely technical and economic. The legal aspects of contract management are not addressed.
Earthworks are subject to hazards that generate risks for the project's objectives, risks that can have repercussions, if they are not controlled or anticipated, on costs, duration and performance.
These risks are linked both to the influence of meteorology and to the existence of hazards related to the geological and hydrogeological environment.
Main hazards (generally unpredictable at the project stage) may be encountered:

- periods of rain or freezing "outside" foreseeable statistics that may cause flooding, torrential rainfall or destructuring of earth-structures
- unpredictable geological or geotechnical phenomena that can cause accidents (landslides, collapses, etc.)
- Unknown cavity areas
- …

These risks may result in major economic excesses. The management of these hazards will have to be based on an optimized study of the resumption of works: sanitation, drainage, modification of earthmoving and planning, in order to limit the additional cost.

Other technical risks can have repercussions on costs, duration and performance if they are not controlled or anticipated. They are generally related to recognition methods, project and work management.

Technical risks encountered:
- insufficient prior investigation
- incomplete or misdirected geotechnical studies
- inadequate work strategy: resources, technical solutions, planning,...
- The periods during which the work is carried out are particularly influential on the risks involved (e.g. earthworks in water-sensitive soils in winter)

The possibilities to face hazards and risks and control their impact require a constant adaptation of the project and the Earthworks strategy.

3. DESIGN / EARTHWORKS PROJECT

3.1. Design of the overall infrastructure

The design of earthworks is part of the design of the overall infrastructure including: Earthworks, draiange, roadbed and subgrade layers, pavement surfacing for the common part and various areas and installations, and also usual engineering structures (underpasses or overpasses), possibly major structures (viaducts), cut and covers, tunnels....

Earth-structures are in interference with all other works or parts of works, which means that they must be considered at all stages of the construction of the whole infrastructure: design and construction.

Layout design

First, the influence of Earthworks in the design of the infrastructure (economic choice) is preponderant in defining the route and longitudinal profile of the infrastructure, which requires preliminary studies (Comparison of routes taking into account external constraints)

Reference France :

- Preliminary design (1000 m band)
- Basic design (300 m strip) submitted to public inquiry

The economic and environmental choice may also lead to comparisons of technical solutions for earthworks (high embankments, high earthworks) with structural solutions: viaducts, cut and covers, tunnels...
These comparisons will require appropriate specific studies.

3.2. Factors to be considered

❖ technical and economic aspects:
- ground configuration and topography
- geology and geotechnics (stability of structures, nature of materials)
- hydrology: dewatering and drainage (provisional and final)
- climatic conditions (precipitation, temperatures)

❖ environmental aspects (see § 2.3)

❖ external constraints :
- heritage
- residents
- restoration of communications (roads) and facilities (water, gas, electricity,...)

3.3. Earthworks and earth-design design

The next phase consists in designing the earth-structures which can be described as elementary: excavations, embankments, pavement support structures, etc.
(upper platform of the earthworks, capping layer, possibly pavement base layers of treated natural materials), which make up the whole linear infrastructure.

A distinction must be made between two phases of design.

In the first phase, the design of earth-structures is determined in terms of stability and deformation. Geotechnical calculation and structural design define the requirements for the properties and functions of the completed structure (geometry, rigidity, bearing capacity, permeability, etc.).

This phase requires specific and heavy studies.

The monitoring and instrumentation of the works will be ensured during the execution of the earthworks, or even during the operation of the structure.

In the second phase, the earthworks design defines the construction process to transform the in situ material (soil or rock) and/or recycled by-products or materials into compacted and durable backfill with the required properties or stability.

Example practiced in Europe

The design of earthworks is governed by EN 1997 (Eurocode 7) and other related standards with regard to stability and deformation terms.

The draft "Earthworks" standards governing the works are all based on the assumption that the constructed earthwork has been properly designed.

European standard reference "Earthworks" Part 1 / General principles and rules (EN 16907-1 § 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.

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.

3.4. THE EARTHWORKS PROJECT

In general, define a project to obtain structures that meet optimal technical, economic and environmental conditions.

❖ To consider:

- The optimal use of the materials of the site, based in particular on geotechnical studies that have made it possible to identify and classify these materials for use according to their nature and condition (in particular water content)

- The possible use of borrow pits opened along the route to compensate for a shortage of materials that can be used as backfill
- The constructive provisions of the excavated material and embankments to ensure the stability and durability of the structures
- The drainage and dewatering project is closely linked to the earthworks project.
- consideration and respect of constraints (environment, interfaces, weather conditions, etc.)
- The resulting masshaul
- The planning of works dealing with the interfaces with other activities: engineering structures, pavements, drainage, etc., taking into account weather conditions

The earthworks project and the identification of materials make it possible to define the methods and techniques to be used to re-use the materials.

3.5. Earthworks studies

There are two types of general studies:

- geometric: ground survey, rights-of-way, structures
- geological and geotechnical: re-use of materials

The studies also concern:

- Geotechnical design (stability of elementary structures, backfill foundations, slopes / settling, consolidation time)
- Platform design (PST, capping layer)
- Drainage and associated dewatering

Reference / Digital development

In the field of infrastructure, the use of a digital model at the design and monitoring stage is increasingly being used.
Note the development of BIM in a number of countries: USA, Middle East, Scandinavian countries, Great Britain,... and more recently in other European countries

The digital model

The digital model is a textured synthesis of the various works, previously modelled in 3D.

BIM (Building Information Modelling)

BIM is a process associated with a digital model based on structured data that allows for collaborative and unique information management.

3.6. Documents

- reports and longitudinal geotechnical profiles
- plans of the structures with longitudinal and cross profiles
- remediation and drainage plans
- masshaul
- implementation schedule

3.7. The earthworks project

We mention below the different parts of the works to be considered in various configurations and the project issue that generally concerns them.

3.7.1. Stripping

- ❖ stripping of excavated areas
  The objective is to extract separately the upper part of the excavated soil from topsoil, which is generally unsuitable for re-use as backfill and reserved as a priority for subsequent reconstitution on the structures.
  - Nature and thickness to be defined
  - Storage in temporary or permanent storage
  - Common use in vegetation (embankments, merlons, restoration of agricultural.... land),

- ❖ stripping of backfilled areas
  The objective is to extract the topsoil part under backfill to obtain a stable base (homogeneous layer of suitable materials).
  - Storage in temporary or permanent deposit
  - Common use generally in revegetation of embankments or other types of vegetation (embankments, merlons, restoration of agricultural lands),

3.7.2. Cuts

Nature of the excavated material: soil or rock

The issue is to excavate the "elementary structure" cut by considering the following elements in particular:

- geometry: height - slopes - platform width
- slope stability
- water incoming, drainage and dewatering
- earthworks platform (bottom of the excavation):
- ○ upper part of earthworks, natural or to be improved (treatment, substitution,...)
- ○ particular constraints: karst or cavity zones, swelling materials....

The objective is an optimal re-use of excavated material to meet the quantity and quality requirements of the project.
Excavated materials are a natural resource for backfill construction. It is necessary to identify the constituent materials: nature, condition, behaviour...
The excavation method should be adapted to the type of materials encountered and their optimal re-use.

3.7.3. Special cuts

These are cuts with particular constraints that will require specific studies:

- ❖ high-height cuts (generally > 15 m) / specific stability studies
- ❖ excavations in aquifers: groundwater level less than 1 m from the subformation level
- ❖ Removals / substitutions that may occur in the construction of the upper part of earthworks at the bottom of the excavation or under the foundation of the embankments

3.7.4. Borrow pits

In the case of a shortage of materials on the site, borrowing areas can be sought.

This is excavated material in appropriate areas within the project right-of-way that is not part of the infrastructure project and is intended to provide additional material suitable for use as backfill. The location of the borrow pit will be the subject of a special study: widening of an excavation, agricultural development, even special permit...
Whenever possible, this solution is an economical and environmental alternative to the use of external materials. However, for many countries it will be necessary to take into account the regulations in force.

3.7.5. Mixed areas

❖ So-called low height areas

- definition: height between arase and " stripped natural ground" ≤1 m
- nature: "excavation / backfill" passages, mixed profiles
- objective: to ensure the continuity of the bearing capacity at the level of the subformation
- special drainage provisions

❖ Cut-and-fill limit

- Boundary area in the longitudinal profile direction
- Requires special constructive provisions: steps,....

❖ Mixed cross profile areas

- Infrastructure areas on the hillside or mountainside
- Requires special studies and appropriate constructive arrangements

3.7.6. Backfill

The objective is to build the "elementary structure" backfill by considering:

❖ geometry: height - slopes - platform width
❖ nature of the materials constituting the backfill (soils, rocks,...)
❖ nature and condition of the supporting soil
❖ stability / slopes
❖ hydrology and hydrogeology of the site
upper part of the backfill

3.7.7. Backfill support

The first study necessary for the construction of the backfill concerns the supporting soil, its nature (soil or rock) and its condition in order to design the stability of the backfill, predict possible settling,...
These studies will lead to specific constructive measures
❖ Common sites: limited stripping or removing the supporting soil
❖ Sites likely to be met:

- on compressible soils (definition - amplitude and duration of settling):
  - technical solutions to be determined
  - reinforcement of existing soils by drainage, substitution, inclusions...
  - pre-loading of backfill
- polluted sites

❖ karst or cavity areas

3.7.8. Special embankments

- heterogeneous backfill under conditions
- backfills made with very dry materials
- underground cavities
- "encaged" backfill: core, shoulder, earthworks upper part

❖ Miscellenaous configurations

- backfill bases in floodable or wet areas
- high embankments (> 15 m)
- backfill on transverse and longitudinal slopes
- backfill in aquiferous or floodable areas:
  - backfill ≤ 1m with water table at natural ground level (flush)
  - backfill in water
- backfill at a landfill or polluted site area
- backfill adjacent to engineering structures and hydraulic structures
- widening of existing embankments
- protective earth mound barrier (attached or not)

❖ Various constitutions

- backfill made with heterogeneous materials (sandwiches)....
- backfill made with very dry materials
- zoned embankments: enbedding and core...

European standard reference "Earthworks" Part 1 / General principles and rules (EN 16907-1 § 6.2)

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:

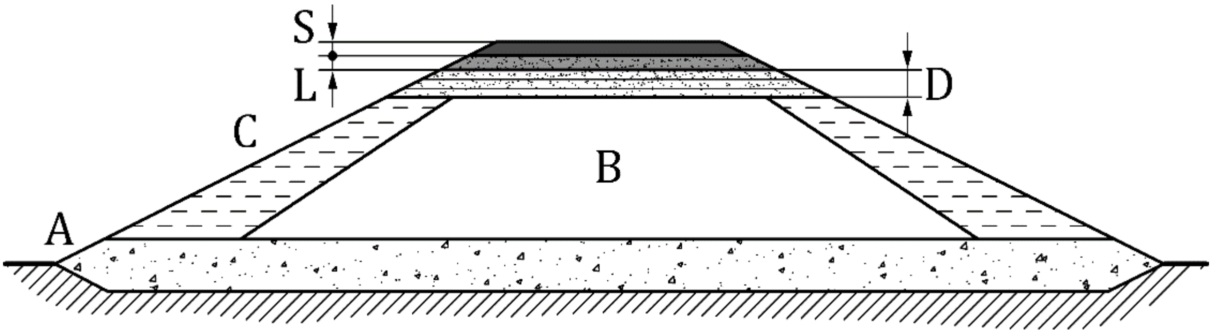


Illustration 5 — Zones of infrastructure fill: general case

- **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.

3.7.9. Final deposits

- landscaping
- final deposits

3.7.10. Upper part of earthworks / Subformation

- nature: natural or treated or granular materials
- dimensioning linked to the couple upper part of earthworks / capping layer
- performance to be defined: bearing capacity as a function of clay content and water content

3.7.11. Capping layer

PIARC Reference Technical Report 2003

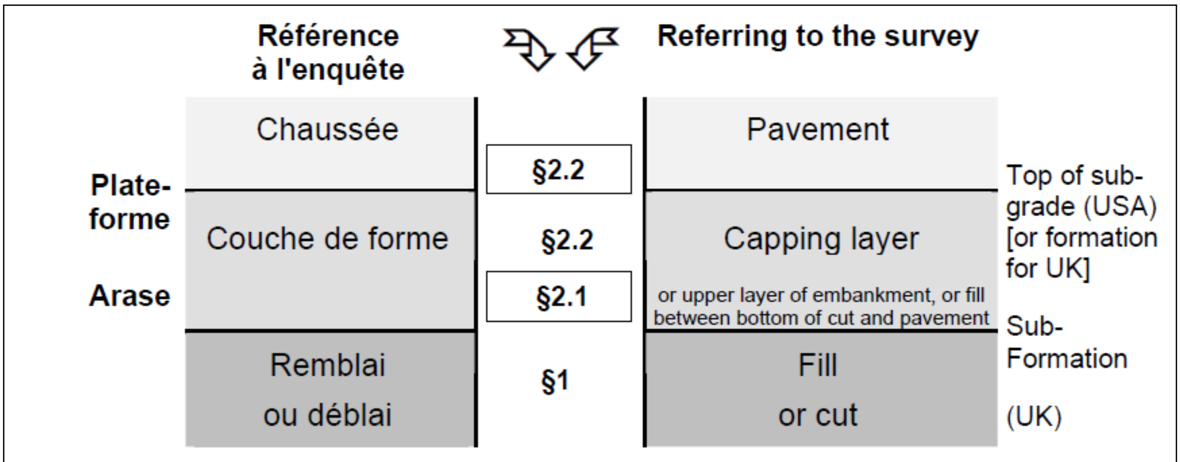


Schéma des différentes couches et surfaces concernées par l'enquête

Sketch of various layers and levels with regard to the survey

This reference from the 2003 Technical Report made it possible to harmonize the existing concepts of the capping layer for different countries.

For this Manual, we recommend to refer to the more complete concept taken into account in the design of pavement structures, represented in paragraph 2.2.

Elements to consider for the capping layer include:

- nature: granular or treated materials (in place or in plant)
- dimensioning: class (/ pavement layers), thickness
- the definition: V_{BS}, hardness / degree of frost susceptibility (LA, MDE), bearing capacity or deflection

Problematic :

- Frost resistant structure
- Granular capping layer
- Capping layers in treated soils
- Participation in the pavement structure

The European standardization project "Earthworks" underlines the interest of the concept of the capping layer.

We present below an extract from the European standard "Earthworks" which explains the definition and role of the capping layer. The capping layer concept is important to make the best use of the project's material resources and to participate in the mechanical and economic design of the pavement structure.

European standard reference "Earthworks" Part 1 / General principles and rules (EN 16907-1 § 6.4)

Definition of the capping layer (§3.1.4)

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

Capping layers (§ 6.4.2)

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.

3.7.12. Water runoff and drainage

❖ Introduction

Earthworks operations modify the grounds and have an immediate impact on groundwater and surface water flows.

Cases to be considered:
❖ restoration of natural flows

❖ water runoff: surface water

- Preliminary works
- water runoff during the construction phase
- In service water runoff

In countries concerned to preserve water resources and their good ecological status, specific measures are studied and planned to compensate for the impacts on surface runoff and prevent possible pollution.

These systems are generally temporary or permanent and correspond to wastewater treatment facilities. This category includes works to restore surface runoff, works to manage runoff on excavated surfaces, and works to treat pollution during the construction phase.

❖ drainage: internal water

In addition to the water runoff structures, a distinction must be made between works and structures dedicated to groundwater management. The presence of groundwater requires special measures to ensure the stability of the earth structures, optimize the re-use of materials in excavation, and ensure the long-term mechanical performance of the structures. These are drainage systems, which may be either temporary or permanent. Drainage water is generally clear water that can be discharged into the natural environment.

❖ Objectives

- different stages: provisory (before and during the work) and final
- capture water to improve soil characteristics for re-use as backfill and to maintain the characteristics of the earth structures.

4. GEOTECHNICAL STUDIES

❖ Objectives of the project

Geotechnical studies are carried out, in whole or in part, at the various stages of the project's evolution:

- Preliminary project
- design
- preparation period before the works are carried out

Geotechnical studies are of crucial importance for the success of the project. They must make it possible to control:

- the re-use of materials
- the stability of the enginering structures
- the design of road structures
- on the other hand, to ensure the stability of the earth-structures

❖ Different stages of studies

- geological and hydrological studies
- geotechnical studies

❖ Documents

- geological maps
- boreholes and geotechnical test logs
- geotechnical reports and studies
- geotechnical long profile

4.1. GEOLOGICAL AND HYDROLOGICAL STUDIES

Existing geological data generally provide indications of the formations encountered at the project site and a first approach to the nature of the materials to be excavated and the risks that may arise.

The geological approach to the nature of the materials to be excavated is particularly important for rocks in order to determine extraction methods: high power shovel, ripping, HRB (Hydraulic Rock Breaker) equipment, mining, sorting...

The analysis of natural geological and hydrological risks will include the following:

- flood or submersible areas,
- seismic zones,
- slope stability,
- natural or anthropogenic cavities,
- risk materials: swelling/shrinkage, erodibility, liquefaction, collapse, with disruptive elements (sulphates, organic matter,...)

It is also necessary to take into account the risks related to climatic conditions

This analysis will most often require specific studies

- Physico-chemical analyses useful in particular for detecting the content of penalizing elements
- Laboratory tests: material identification, formulation and processability studies

4.2. GEOTECHNICAL STUDIES

As mentioned above, the main purpose of geotechnical studies is to identify materials in order to determine their reusability opportunities in the project.

4.2.1. Studies on the re-use of materials

They are based on the results of the following main operations:

- drilling: shovel, auger, core drilling
- laboratory tests: identification, treatment study
- in situ tests: test section (or site test), if justified by technical interest

4.2.2. Material identification

The identification of materials makes it possible to predict which materials are suitable for use under certain conditions depending on their nature, state and foreseeable behaviour and final destination in the structure, with reference either to a material classification (see paragraph 4.3) or to specific tests.
The earthworks project and the identification of materials make it possible to define the methods and techniques to be applied to use the materials.

4.2.3. Stability studies: cuts, backfills, backfill foundations

Main tests :

- core drilling
- penetrometer
- pressure meter
- laboratory tests: triaxial, oedometer, shear
- geophysical tests

4.2.4. Execution studies

- ❖ Taking into account the final data of the project
- ❖ Implementation plans and possible calculation notes

4.3. CLASSIFICATION OF MATERIALS

From the identification it makes it possible to predict the conditions of use of the materials for different destinations (backfill bodies or capping layers for example), according to their nature, state and behaviour.
The classification must allow the materials studied to be integrated into a family with similar behaviours.
See PIARC reference at the end of this paragraph and in general Part 2A which deals with materials.

4.3.1. Classification of natural materials:

➢ Two main groups are considered:

❖ Soils Group
Soils are generally divided into classes

- Fine soils
- Sandy and gravelly soils with fine
- Soils containing fines and large elements

- Soils insensitive to water.

❖ Rock Materials Group

The classification of rock materials is mainly based on geology.

➢ The use of materials requires special approaches

❖ Case of materials suitable according to specifications

❖ Case of materials at the limit of specifications: marginal materials

- Evolutionary, degradable, fragmentable materials
- Materials with special compounds
- Very wet materials
- Very dry materials
- Very clayey materials
- Poorly structured homometric materials (sand, dredging sand, dune sand)

❖ Special case of lateritic materials

Materials encountered in majority in many countries around the world.

4.3.2. Alternative materials

These include "artificial" or recycled materials that can be used in road technique, mainly near production or storage sites.
At the same time, this use makes it possible to eliminate waste.
We present a list of these materials inventoried around the world and on which we come back for more information in Part 2A.

❖ Industrial by-products / thermal and chemical processes
- blast furnace slags
- steel slags
- fly ash
- slag, steel slag
- foundry sands
- phosphogypsum
- titanogypsum

  bottom ash from household waste incineration: Municipal incinerator bottom ash1 - excluding fly ash- (MIBA)

❖ Mining by-products
- coal shales
- potash mine shales

❖ Demolition products
- concrete and other building demolition materials
- concrete from road demolition
- bituminous pavement demolition materials

❖ Natural materials containing organic materials

❖ Miscellaneous materials out of specification
- mine and quarry wastes
- sewage sludge

- dredging sediments
- paper mill waste
- potash
- …

- Residues from various sources
  - Tires
  - Glasses
  - Plastics
  - …

4.3.3. Other special materials

- Topsoil
- Polluted soils

Concerning the classification of materials, the 2003 Technical Report "Limits of use of natural soils, specifications and controls in earthworks" had identified three types of soil classification.

Reference - Technical Report PIARC 2003 / Types of used classifications

It appears possible to distinguish three types of soils classification:

A: general classification of soils which is not connected directly to specifications of employment, but rather with privileged fields of application with concerning the classes of soil likely to generate difficulties, even whose employment is disadvised.

They are generally the classifications of soils derived rather directly from classification USCS or HRB. In this case, one can quote the example of Germany and Switzerland. With these classifications, it returns to the engineering and design department charged to draw up the project to define the soils which will be employable for this project and which condition. So the specification is not generalizable with all the projects, but has to be thus adapted to each particular project under the responsibility of the geotechnician engineer.

B: classification of all the soils suitable to be met and connected directly to a grid of the possible re-employment as fill or capping layer possibly supplied with particular methods of implementation to make the soils acceptable as fill or capping layer. It is in particular the case of the classifications of soils used by France and Portugal.

These classifications are specialised for the field of the earthworks and it frequently happens that in the same country, one has a classification of different reference according to specific problems (for example in France for the soil mechanics or the management of resources materials).

C: a third type of classification appears to be that developed by England which starts from categories of employment (for example soils usable as fill, soils usable as fill close to a bridge ...) to define the characteristics that the soils must have. This type of classification opposites the reasoning which is not any more "what use can one makes with this soil?", but rather "for a determined need, what are the characteristics of the acceptable soils". So, this classification constitutes a specification for the contracts and is integrated besides in the Specification for Highway Works (SHW) in series 600 (earthwork). As in classifications of the type B, this classification is obviously dedicated to the projects of earthwork and there is another used in soil mechanics.

5. PREPARATION PERIOD BEFORE WORK

5.1. IMPORTANCE OF STUDIES AND PRIOR INVESTIGATIONS

They are made in addition to those carried out at the design stage to validate and specify the data of the preliminary project.

- Importance of specific preliminary studies to define the methods and techniques to be applied to use the materials
- Adapted geotechnical and geological surveys
- Important physico-chemical analyses, particularly to detect the content of penalizing elements
- Laboratory tests: material identification, formulation and suitability to treatment studies
- In situ tests, test sections, or even test site where the pay back of its cost can be done

5.2. STUDIES TO BE CARRIED OUT

5.2.1. Use of data from Market documents

5.2.2. Additional geotechnical studies:

- surveys and tests
- reports
- conditions for the re-use of materials
- binder treatment studies
- stability studies
- geotechnical longitudinal profile

5.3. IMPLEMENTATION DOCUMENTS TO BE DEVELOPED

- masshaul
- work schedule
- plans: longitudinal and cross profiles
- work statements (for each task): technique, methods and means of execution

6. REALIZATION

In this paragraph we present the list of operations, methods and techniques to be considered in earthworks and the construction of earths-tructures.
Refer to Part 2D of the Manual for further technical developments.

6.1. PRELIMINARY OPERATIONS

- location of rights of way
- clearing and preparation of rights-of-way
- structure location
- utilities and road diversion
- construction site tracks and temporary diversions
- temporary site drainage works

6.2. METHODS OF IMPLEMENTATION

❖ adjustment of the water content (if necessary): watering, humidification, aeration, treatment with binders, temporary drainage
❖ compaction :
- energy applied according to:
  - structure to be built
  - layer thickness
  - compactor speed
  - compactor class
- compaction of backfill edges

❖ constructive measures:
- cuts slopes: weight masks and/or drains, draining spurs, horizontal drains, tie rods, etc.
- platform in excavated material: draining trenches
- backfill: caging, sandwich
- water-insensitive or draining backfill bases
- compressible backfill bases: depending on the nature and thickness of the compressible materials and the tolerated settling (amplitude and duration):
  - pre-loading and/or vertical drains
  - phasing of the backfill rise
  - trenches or draining layers
  - lightweight embankments
  - substitution of materials
  - inclusions, columns, studs...

6.3. THE ADEQUACY OF EARTHWORKS EQUIPMENT

The project for the use of materials in earth movement and planning determines the choice of techniques and equipment and the conditions for carrying out earthworks operations to be considered, as listed below:

Set of pictures 2

6.3.1. Extraction and loading

❖ **Soft soil excavation**

- current extraction and loading equipment:
  - hydraulic excavators with all-round haulage
  - scrapers (with bulldozer-pusher) with short haulage transport
  - other equipment: wheel loaders or tracked loaders, draglines,...
- specific problem:
  - presence of water, erosion, freezing....
  - material bearing capacity
  - temporary slope stability
  - sorting of materials (clayey-silt, sandy, gravelly, wet, dry...)
  - work protection
  - ...

❖ **rock excavation**

- material :
  - extraction: drills and blasting - displacement (bulldozer) – Hydraulic rock breaker (on hydraulic excavator)
  - loading: hydraulic excavators: with all-round haulage
  - long distances: dumpers, road trucks,...
  - other equipment: tracked loaders,...
- specific problem:
  - Maximum D (mm) of the raw material

- temporary slope stability
- material sorting (rocky / clayey)
- work protection
- ...

6.3.2. Haulage

- commonly used material:
- soft materials - short distances: scrapers
- all materials - all distances: trucks
- specific problem:
- construction site tracks:
  - provisory or integrated
  - sizing - "all-weather" trafficability - maintenance
  - abrasivity
  - specific treatments
- control of dust emissions generated by the circulation of machine
- watering
- crossing existing roads
- traffic on the Upper Part of Eartworks (UPE) or on the capping layer

6.3.3. Implementation of backfill materials

❖ **preparation of the supporting ground (ordinary foudation)**
- equipment: bulldozer - compactor
- specific problem :
- flood-prone or wet areas
- foundations with insufficient bearing capacity: substitution or thick first backfill layer

❖ **levelling**
- equipment :
- bulldozer with dumper haulage
- grader or bulldozer with scraper transport
- other equipment
- specific problem:
- D maxi (mm) of the material
- control of the layer thickness

❖ **water inflows**
- watering :
- equipment: "carptail" or ramp sprinkler
- specific problems :
- control of the spread quantity
- runoff

❖ **humidification**
- equipment: "Buried" sprinkler
- specific problem:
- imperative use for capping layers or technical backfills
- need mixing for capping layer or technical backfill

❖ **compaction**
- equipment :
- vibrating roller with smooth cylinder: all classes of materials
- vibrating compactor "padfoot": clay and silt materials (sandy excluded)

- static compactor "padfoot": silty clay materials (sandy excluded)
- specific problems :
  - adequacy between the class of the compactor and the nature and use (compaction energy) of the material
  - compaction of slope edges (excess meter, “W” method)
  - necessity of the tachograph: speed, distance covered (For example Q / S GTR method France)
  - scanning control: (GPS techniques)

❖ **treatments with binders**

- equipment
- binding agent spreader: servo-control - variable spreading width
- mixers :
  - ploughs with ploughshares and bulldozers: lime treatment: ordinary backfill - pre-treatment
  - pulvi-mixer (horizontal shaft): hydraulic binder treatment for subgrade - technical backfill – upper part of earthworks and all classes of materials
  - fixed mixing plant: hydraulic binder treatment for capping layers of sandy materials
- specific problems :
  - precision of the spreader (coefficient of variation)
  - D maxi (mm) of the material
  - mixing depth (homogeneous distribution of the binder)

6.4. REALIZATION TECHNIQUES

6.4.1. Mechanical treatment of materials:

The main treatments concern sorting, tracking, ripping, screening, crushing (in place or in the plant),...

6.4.2. Treatment by mixing:

This applies in particular to grain size correctors, material additions (correction of water content)

❖ **Adding water**

- watering
- humidification: need to mix in the case of capping layer treatment

❖ **Decrease in water content**

- drainage (half platform operation)
- aeration: need to stir (mixing)
- addition of dry material: need to mix
- lime treatment (or other suitable reagent): need to mix

6.4.3. Treatment with binders (lime and/or hydraulic binder)

Refer to Part 2B of the Manual for further technical developments

❖ **Elements to consider:**

- Treatment products
- Materials suitable for treatment
- Quicklime treatment
- Hydraulic binder treatment
- Mixed treatment with lime and hydraulic binder
- Processing equipment (See § 6.3.)

- Specific treatment studies
- Controls

- Environmental protection
- Safety and security

❖ **improvement of geotechnical characteristics**
- insensitivity to water:
  - lime for silty clay materials
  - hydraulic binder for sandy materials
- mechanical characteristics (resistance - cohesion - frost resistance)
  - lime and hydraulic binder silty clay materials (possibly lime only)
  - hydraulic binder for sandy materials

❖ **methodology**
- treatment in the extraction area (transport of treated materials)
- treatment in the area of use (transport of natural materials)

❖ **Treatment, elimination of penalizing elements**

6.4.4. Special constructive provisions

❖ **On backfill**
- high embankments
- encagement
- sandwich
- steep slope
- base in floodable or wet areas
- slope compaction (excess method, "W platform")

❖ **Bottom of excavation form**
- unsuitable materials (very plastic clays...)
- swelling materials

❖ **Upper part of earthworks / subformation level**
- constitution (granular, treated)
- design (class, thickness, water and frost sensitivity)

❖ **capping layer**
- constitution (granular, treated)
- design (class, thickness, water and frost sensitivity)

6.4.5. Meteorology and earthworks

To consider:
❖ Sensitivity to water
❖ Trafficability
❖ Extreme weather conditions

7. CONTROLS ON THE EXECUTION OF THE WORK

7.1. GENERAL INFORMATION

OBJECTIVES: TO CONTROL THE EXECUTION OF THE WORK AND THE CONFORMITY OF THE STRUCTURES

Type of controls

There are two types of controls:

- By tests
- Visuals

BY TESTS

- of convenience that make it possible to adapt and validate the execution process as well as the proposed materials (*)
- monitoring, which ensure that the validated processes are properly carried out
- information that makes it possible to detect any anomalies
- compliance, which make it possible to verify that the required quality is achieved in order to grant acceptance of works

VISUALS

In the field of earthworks, visual inspection is an essential complement to test inspection. To be effective, they must be carried out by qualified personnel

DEFINITION OF TESTS

The tests are defined by:

- the nature of the process (compaction, treatment, etc.)
- the type of structure (or part of a structure) or area of application
- their frequency for each part of the structure (number, mesh size, etc.).
- the required threshold
- Control tests should generally be carried out in accordance with the standards in force in the country and in the absence of such standards on validated reference sheets or by following specific operating procedures if required.

7.2. ORGANISATION OF CONTROLS

It is proper to establish a **quality assurance** program that will include the **Quality Control Plan**.

This global system is practiced in many countries. The following reference note illustrates the main advantages.

Reference / Note IFSTTAR (France)

The notion of Quality Assurance is a notion that dates back to the 1970s in France. This concept is based on the development of a methodology that makes it possible to manage the various phases of work execution by implementing a control policy that makes all project stakeholders (project owner, project manager, company) responsible, in order to avoid facing a non-compliant structure at the end of the work.
The methodology involves identifying the different periods and parts of works that may generate anomalies, and involves the implementation of controls distributed between the company and the Engineer. Each control phase is validated by the project manager on behalf of the project owner, which allows the work to continue while controlling deadlines, costs and performance.
Framework documents exist to specify the vocabulary, the organization of methods and the chain of responsibility between the different actors.

7.3. Quality assurance and control

The organisation of controls is precisely defined in various "quality" documents to be established before, during and after earthworks.

The process depends on the type of contract or work contract that defines the applicable clauses for the organization of controls. In the field of earthworks, the recommended process that is generally appropriate is as follows.

The Engineer precisely defines the controls.

The Contractor shall draw up the organisational diagram of the Quality Assurance Plan (QAP) which shall indicate, inter alia, the organisation chosen to perform the tests and the apparatus and test methods envisaged.

Carrying out controls

The test inspections are divided into:

- the so-called "interior" control depending on the company, which includes:
  - internal (follow-up)
  - external (reception)
- the so-called "exterior" control at the expense of the Contract Manager (or the Engineer)

The following extract from European standards is a proposal for a quality organisation, representative of what is practised in a majority of countries.

Reference European standard "Earthworks" 5 / Quality control (EN 16907-5 § 3, 4 and 5)

Définitions (§ 3.1.41 et 42)

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

Quality assurance

All those 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

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

Quality Assurance Programme (§4)

Quality Assurance [QA] refers to the overall system for assuring project quality with Quality Control [QC] being one element of a comprehensive QA programme.

A comprehensive construction QA programme consists of the following core elements:

1/ Quality Conrol

2/ Acceptance: All factors [i.e. sampling, testing and inspection] to evaluate the degree of compliance with contract requirements

3/ Resolution of non-conformances: A process for resolution of non-conformances should be unbiased and timely.

Quality Control Plan (§5)

A Quality Control Plan for earthworks shall as a minimum include:

1) Sampling and test procedures, including:
- test locations
- frequency of testing
- test methods and standards to be adopted
- extent of data to be collected and storage requirements thereafter
- methods and criteria for acceptance

2) An organization chart identifying all relevant personnel and key tasks; in particular who is responsible for quality overall and for individual elements such as testing

3) Procedures for reviewing samples, certificates etc.

4) Visual observations and inspections

5) Document control procedures

6) Procedures for recording non-conformance and what corrective actions are to be undertaken.

Approaches to Compaction Control (§ 7)

General

Two main approaches of specifying compaction exist across Europe, which are Method specification and End product specification, as described below and in prEN 16907-3 and as summarized in prEN 16907-1.

Method Specification

Method Specifications requires the production and placement of earthworks using specified materials, specific types of equipment and methods stated in the contract.

End product Specification

End product Specifications require earthworks to be constructed to achieve specified engineering criteria. In this form of specification the earthworks practitioner responsible for construction has responsibility and latitude in determining the materials, procedures and equipment used to produce the product.

7.4. Controls and means to be associated with the technical specifications linked to the execution of the earthworks:

Controls of the execution of earthworks are carried out during the various phases of the work: soil investigation, preparation of rights-of-way, stripping, extraction of materials, implementation of materials, etc.

The essential controls to ensure the quality of the work - to be applied regardless of the size of the site - are as follows.

7.4.1. geotechnical control

The identification of materials is the essential basis for earthworks to enable the optimal use of materials. It is very important to be able to refer to a **classification of materials** that gathers geotechnical data from feedback. It is recommended to associate the hydric state with the identification to specify the conditions of use of the materials

This control is carried out:
- ❖ before the start of earthworks operations
- ❖ during the earthworks

The main tests used are as follows:
- the water content
- the Proctor curve
- immediate bearing capacity IPI and after immersion CBR
- granulometric analysis
- plasticity
- hardness for rocks
  - impact strength (LA) and attrition strenght (MDE)
  - degradability
  - fragmentability

7.4.2. Monitoring of compliance with masshaul

7.4.3. compaction control

The densification of materials mainly used as backfill is sought to reduce the void index and limit the risk of settling.

Compaction is carried out at an optimal water content according to the Proctor curve

- SPT is used for backfill and capping layers
- MPT is used in the particular case of very dry materials (in some countries)

It should also be noted that the MPT is used for pavement base courses composed of treated soils (refer to the "Treatments" section of the Manual)

❖ Proctor Test

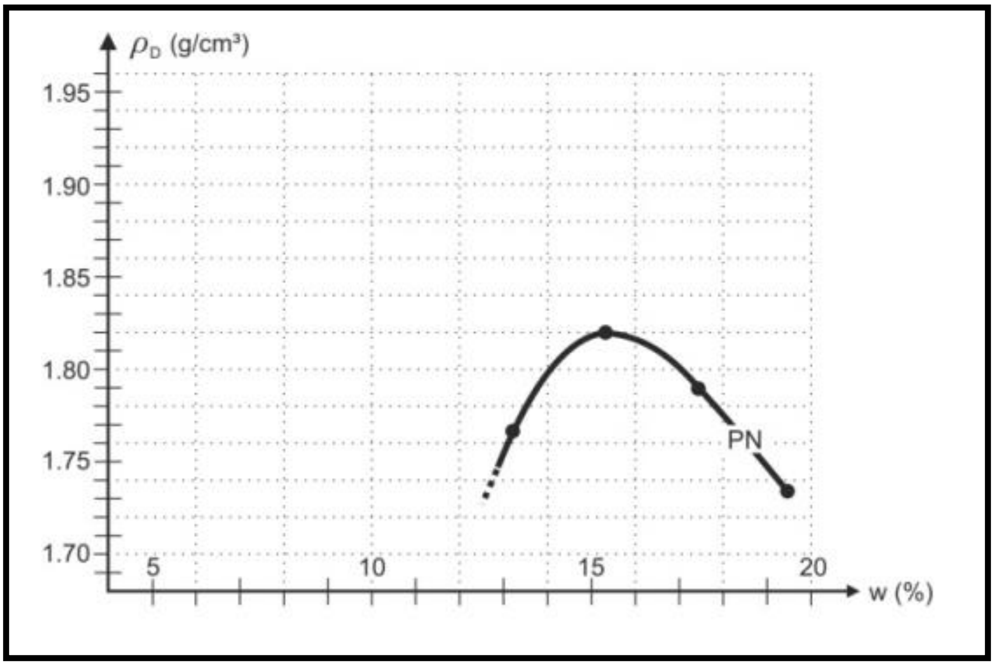


Figure 5 - Example of a Proctor curve

ρd dry density (g/cm3)

W water content (%)

❖ Parameters for characterizing water status

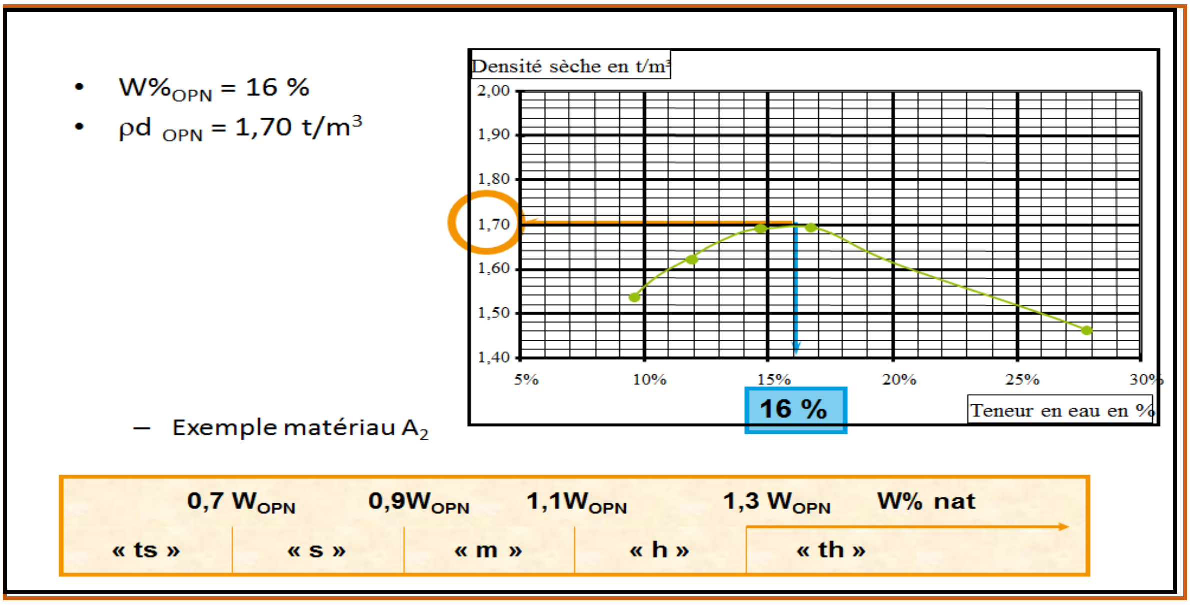


Figure 6 - Example of Standard Proctor test results (loess A2)

(GTR France reference / water content state thresholds)

The main tests used are:

- the control of the density in place:
- control of the level of compaction

7.4.4. control of bearing capacity and deformability

7.4.5. Controls specific to the treated materials

- Binder control
- Visual inspection of mixing:
- Control of mechanical characteristics on specimens (manufactured in the laboratory or drilled in place):

7.4.6. control of te equipment

- Compactors
- static :
- vibrating
- controllographer :
- Treatment equipment
- binder spreader :
- mixers :
- water spreader:

7.4.7. Other types of control

They concern in particular:

- the remediation during the construction phase,
- the geometry of the structures
- the impact of earthworks on the environment.

7.4.8. Special techniques

For the execution of works using particular techniques (very high backfill, re-use of evolving materials, reuse of organic soils or industrial by-products, hydraulic backfill, etc.), the control will be defined with reference to the recommendations specific to these techniques.

7.4.9. Monitoring of the construction of embankments

Particular attention should be paid to the construction of embankments at all sites, in particular where stability and/or settling are considered to be decisive. The installation of appropriate instrumentation will then be necessary.

7.5. CONTROLS CARRIED OUT DURING THE EXECUTION OF EARTHWORKS

The main controls are to be carried out in the different parts of the earthworks listed below.

❖ Standard backfill foundations
- Clearing operations – stumps removal - demolitions
- Stripping
- Purge (Material substitution)
- Provisional sanitation and drainage
- Compaction and bearing capacity of the foundation

❖ Extraction - excavated material
- Clearing operations – stumps removal - demolitions
- Stripping
- Provisional drainage
- Extraction of materials
- Slope and structure stability
- Geometry
- Subformation level
- Rock excavation

❖ Backfill
- Materials
- Slope and structure stability
- Compaction
- Geometry

❖ Upper Part of Earthworks (PST) – Subformation level

❖ Capping layer

❖ Treated materials (backfill, PST, capping layer)

7.6. TEST METHODS

The "test methods" for earthworks control are divided into three groups:
- identification control of materials;
- implementation control;
- equipment control.

They include the following headings:
- object ;
- field of application ;
- principle of the test;
- expression of results ;
- interpretation ;
- particularities and time for response.

8. TECHNICAL SPECIFICATIONS AND STANDARDS

Main specifications, recommendations and regulatory texts issued by a number of countries in Europe and worldwide.
See Annex 1.1 for references specifically used in the Manual.

9. TERMINOLOGY / GLOSSARY

See Annex 1.2

ANNEXES PART 1

Annex 1.1 European Earthworks Standardisation

The purpose of this Annex is to briefly present the work on the development of the European standard "Earthworks", a standard that provides a recent reference for best practice and guidance in the field of Earthworks.

This reference is one of the main threads in the various chapters developed in the Earthworks Manual. It should be noted that the normative aspect is not taken into consideration in our discussion.

I / Background information presented in the 2012 PIARC Technical Report

The PIARC Technical Report published in 2012 "Innovative Approaches for the Use of Locally Available Natural Marginal Materials" referred to the European context in this field.

European context

In all areas of construction, Europe is adopting specific standards that will eventually replace national standards. To this end, the European Committee for Standardisation (CEN) sets up Technical Committees set up to draw up the bodies of standards corresponding to the various fields of activity.

In the road sector, normative work is relatively advanced with regard to pavement structures, in particular through TC 227 "Road Materials".

It is more recently that the European economic actors of the Earthworks activity have approached the CEN to create a Technical Committee dedicated to this specific activity, which has been well identified.

Progress in the European standardisation of earthworks

The CEN took its decisions in two phases.

The creation in December 2007 of a Working Group (WG 203) to establish a report on the relevance of a body of standards specific to earthworks, without significant overlap with the work of existing CTs.

On the basis of the report prepared by WG 203, CEN decided in March 2009 to create the TC 396 Technical Committee.

Technical Committee 396

Title: Earthworks

Scope of works : Terminology for earthworks (terms and definitions); Test methods (characterisation for earthworks of natural soils and rocks in laboratory and in situ including improved soils treated with binders or lime or other "additives" used in earthworks. Classification systems of soils and rocks suitable for use in embankment construction, possibly leading to a unified classification system or principles/rules for classifying soils and rocks for earthworks purposes; Characterisation of extraction ability ("excavatability"); Design of earthworks; Quality control of works and monitoring.

II / Progress of the Draft European Standard "Earthworks" in 2017

❖ Ongoing document development work

In 2017, the work concerns the Draft Standard "Earthworks".

(EN 16907- Parts 1 to 7)

The documents were prepared by the CEN/TC 396 Technical Committee "Earthworks", whose secretariat is provided by AFNOR.

(See organization in attached document)

The documents are divided into 7 parts:
- *Part 1: General Principles and Rules* ;

- *Part 2: Material Classification;*

- *Part 3: Construction Processes ;*

- *Part 4: Treatment with lime and/or hydraulic binders;*

- *Part 5: Quality Control;*

- *Part 6: Dredged Hydraulic Backfill Field;*

- *Part 7: Hydraulic investment of mining surpluses.*

Project development work for Parts 1 to 6 was completed in 2016. After investigation, the documents were forwarded to CEN in 2017 with a view to organising a formal vote by European countries.

The results of the formal vote held in 2018 were largely favourable for all standards.

The English version is expected to be published at the end of 2018. This will be followed by publications in French and German versions.
Work on the development of Part 7 is still ongoing.

❖ Other work launched

It should be noted that two working groups were created in 2017 with prospective objectives initially concerning the following themes:

- Test methods specific to earthworks

- The use of "alternative materials" (industrial by-products, recycled materials, waste, etc.)

III / General information on the European Standard "Earthworks".

Extract from Standard EN 16907 Part 1 "General principles and rules"

Scope of application

- **Introduction**

The European standard (Part 1) provides definitions, principles and general rules for planning, design and specifications of earthworks. It introduces the other parts of the standard, which must be used with Part 1.

Earthworks is a civil engineering process that aims to create earthworks by modifying the geometry of the earth's surface as part of construction projects or for other activities.

They are characterized by the need to use available natural or recycled materials and to treat them appropriately to achieve the prescribed properties.

This standard applies to all types of earthworks except as follows:

- certain types of work such as trenching and small earthworks can be organised using simplified or specific rules;
- some structures, such as dikes and dams, require earthworks with specific design and construction requirements: these requirements may go beyond the rules of this standard.

In view of the variability of subsoil and climate conditions in Europe, and the different national contractual provisions, specific rules have been established in different European countries.
For this reason, this European Standard defines the basic rules for achieving the objectives described above. Information Annexes B to H of this document provide examples of national practices that follow these rules.

- **Scope of application**

The fields of application of earthworks are associated:

- transport infrastructure (roads and motorways, railways, inland waterways, airports);
- platforms for the construction of industrial, commercial or residential buildings;
- hydraulic installations, flood defence and coastal protection works;
- port and airport areas, including the construction of embankments in the water;
- river dikes and medians reclaimed from the sea;
- earth and rockfill dams;
- embankments created by hydraulic backfilling;
- acoustic or visual screens and other earthen structures not carrying a load:
- to the landscaped embankments;

- the backfilling of open-pit mines and quarries;
- tailings containment dikes.

The standards developed by CEN/TC 396 are divided into several parts that correspond to the different stages of earthworks, namely planning, execution and control.

They should be taken into consideration when carrying out the work.

These "earthworks standards" do not apply to environmental planning or geotechnical calculation, which determine the required shape and properties of the earthwork to be built (these aspects are covered by other European Standards).

They apply to the design of earthworks materials, the execution, supervision and control of earthworks, in order to ensure that the completed earthwork meets the geotechnical calculation.

Terms and definitions

Excerpts

Earthworks
Civil engineering processes that modify the geometry of the ground surface by creating stable and durable earthworks

Clay structure
A civil engineering structure, consisting of soil, rock, by-products or recycled materials, produced by earthworks (excavation, backfill).

Design of an earth structure
Definition of a structure in accordance with the EN 1997 standard to meet the functional requirements of its future use

Earthworks design
Definition of the construction process to produce a specified earthwork

Materials
Soils, rocks, industrial by-products and recycled mineral materials used in earthworks for the construction of earthworks.

Treated (backfill) material
(Backfill) material modified by the addition of a binder

Inadequate material
Backfill material unsuitable for use in its current state because its properties before compaction do not meet the requirements of the technical specifications for earthworks. These materials can become adapted after a treatment to adjust the soil properties

Classification
Definition of classes and assignment of materials to classes with similar properties for earthworks
Clearing
Linear earth structure formed by an excavation process

Backfill
A general term used in this standard to describe all earthworks formed by the placement of backfill material in a controlled manner for technical purposes (including infrastructure backfills, backfill backfills, platforms, etc.)

Backfill structure
Earthwork made by backfilling (associated with linear infrastructures or platforms)

Backfill area
Subdivision of a backfill into several parts, including the base, core, shoulders and upper part

Compaction
Densification of the backfill material by a mechanical process to obtain the prescribed properties of the backfill

Compactness or degree of compaction (of the backfill)
Ratio between the dry density in place of the compacted backfill material and the maximum dry density obtained by means of a standard laboratory compaction test

Compaction effort
Aggregate measurement of the force applied to compact a backfill layer, reflecting: compactor mass/m2, number of passes, roller speed, vibration frequency and layer thickness

Moisture content
Ratio between the weight of water contained in a particular sample and the weight of dry soil

Trafficability

Ability of the surface of a material to withstand the passage of earth-moving machinery

Capping layer
Specific transition layer, located in the upper zone of the earthworks, placed under the superstructure. The capping layer is an integral part of the earthwork

Superstructure

Civil engineering structure installed on the earthwork (example of superstructures: pavement, railway track, buildings, gantries, etc.)

IV / CEN Organisation / TC 396 "Earthworks" (2009 to 2018)

The European standard "Earthworks" was developed by the CEN European Technical Committee TC 396. This committee includes more than 50 registered expert members from a majority of European countries. About 30 active TC 396 members from 13 countries followed the development work organized into working groups and task forces, the general organization of which is shown in the following table.

NAME	Country	Function	Organization	Company name
RAOUL Guy	France	President	AFNOR / SPTF	SPTF
SMERECKI Benoît	France	Secretary	AFNOR	AFNOR
MAGNAN Jean-Pierre	France	WG Moderator Part 1 Coordinator Parts 1 to 7	AFNOR	IFSTTAR
GILBERT Peter Peter	UK	Expert Task Force P.1	OHIH	ATKINS
PARILLA Alvaro	Spain	Expert Task Force P.1	AENOR	Ministerio de Fomento
KAYSER Jan	Germany	Expert Task Force P.1	DIN	
HERVE Sébastien	France	Expert Task Force P.1	AFNOR	CEREMA
VOGEL Wolfgang	Germany	WG Moderator Part 2	DIN	DB AG
MOLLIER Thierry	France	WG Moderator Part 3	AFNOR	EGIS
PUIATTI Daniel	France	WG Moderator Part 4	AFNOR	DPST
KIDD Alex	UK	WG Moderator Part 5	OHIH	Highways Agency
THEYS Franck	Belgium	WG Moderator Part 5	NBN	OCW
VAN DER MEER Joop	Netherlands	WG Moderator Part 6	NEN	Van Oord
CAMBRIDGE Mike	UK	WG Moderator Part 7	OHIH	Cantab Consulting

Appendix 1.2 Technical references

The purpose of this Annex is to cite the main technical references of the Manual. Other more specific references are listed in detail in the various developments in Part 2.

PIARC references / Technical reports of the Earthworks field (DP : je suppose que les intitules sont ceux des versions anglaises des documents)

- Optimal use of local materials in road excavations (2017- R04FR)
- Innovative approaches for the use of locally available natural marginal materials (2013 - 2012R37FR)
- Vulnerability of geotechnical infrastructure to climate change and adaptation measures according to geographical context (2012 - 2012R04FR)
- Anticipating the effects of climate change on geotechnical road structures (2008 - 2008R12FR)
- Representative indicators of the condition of geotechnical structures for road asset management (2008 - 2008R01FR)
- Promoting the optimal use of local materials (2007 - 2007R09FR)
- Limits of use of natural soils, specifications and controls in earthworks (2003 - 12.12.BFR)
- Roads in desert environments (1991 - 03.03.03.BFR)
- Recommendations on risks associated with slopes for roads (2004 - 12.13.BFR)
- International Symposium on Internal Drainage of Pavements and Subgrade (2000)
- Recommendations for the design and execution of road embankments (1999 - 12.03.BFR)
- Marginal materials - State of knowledge (1989 - 02.04.BFR)
- Execution of aggregate tests (1987)
- Conducting tests on geotextiles (1987)
- In situ evaluation of shape-layer materials (1995 - 12.01.BFR)
- Lightweight backfill materials (1997)

- ❖ Landslide - Risk Assessment Techniques (1997 - 12.04.BFR)

- ❖ Equipment and execution techniques specific to soil treatment works (12.05.BFR)

- ❖ Contribution to the management of risks associated with slopes (2000 - 12.11.BFR)

Technical references contained in the complete normative corpuses dedicated to Earthworks

- ❖ **European standards (CEN)**

- Standard **(EN 16907- Parts 1 to 7)** "Earthworks" (Publication end 2018)
  - To be noted in the annex to the standard: documents on national practices Austria, France, Germany, Norway, Spain, Sweden, UK.
- Standards-Eurocodes
  - **EN 1997-1, Eurocode 7** - Geotechnical calculation - Part 1: General rules
  - **EN 1997-2, Eurocode 7** - Geotechnical calculation - Part 2 : Land recognition and testing

- ❖ **USA Standards**

  - AASHTO : American Association of State Highway and Transportation Officials
  - ASTM : American Society for Testing and Materials
  - USCS : Unified Soil Classification System

References specific guides Earthworks and earth structures

In particular France:

- GTR Technical Guide - Realization of embankments and capping layers (2nd edition July 2000)
- GTS Technical Guide - Soil Treatment with Lime and/or Hydraulic Binder (2000)
- Design and execution of earthworks (SETRA / CFTR) March 2007 - 3 fascicles

Guides and Standards specific to other countries:

The technical references contained in the standards or implementation guides of some countries are also cited in Part 2 of the Manual.

Bibliographies

The bibliographic sources (articles, presentations, etc.) to which the Manual refers include the following:

International seminars "Earthworks in Europe"

1 / Paris, October 2005

2 / London June 2009

3 / Berlin March 2012

4 / Madrid June 2018

PIARC International Seminars associated with Technical Committee TC.4.4

In particular:

Rabat International Seminar June 2014

"Earthworks and pavements in arid and semi-arid environments"

PIARC Technical Report 2012R37FR

Cited in the report:

- "Laterites and lateritic gravelly rocks" LCPC/ISTED, 1983
- "Practical guide to pavement design for tropical countries" CEBTP
- Tremti 2005 - Paris, France, 24-26 October 2005
- Tremti 2009 - Antigua, Guatemala, November 11-13, 2009

Documentary resources "Engineering Techniques".

Headings

- Earthworks and geotextiles
- Geotechnical engineering
- Valuation of industrial by-products in civil engineering

Appendix 1.3 Abbreviations, symbols and terminology

A 1.3.1 Abbreviations

The main abbreviations used in the Manual are listed in Tables 1 and 2
They come from two sources of references.

Reference European standard "Earthworks"

CBR	CBR (California Bearing Ratio) test California Bearing Index test
CBRi	Submerged CBR test
CCC	Continuous Compaction Control
CPT	Cone Penetrometer Test (static Cone Penetrometer Test)
DG	Degradability test
TPD	Dynamic cone Penetration Test
FR	Fragmentability test
IPI	IPI test or immediate bearing index test
LA	Los Angeles Test
CVD	Moisture Condition Value Test
IMM	Micro-Deval Test
SPT	Standard Penetration Test

Table 1

Reference PIARC Technical Report (2013 - 2012R37FR) "Innovative approaches to the use of locally available natural marginal materials"

OPN	Optimum Standard Proctor
OPM	Optimum Modified Proctor
MO	Organic matter content
PLT	Plate loading test
LHR	Hydraulic road binder
PST	Upper part of the earthworks (*Subgrade)*
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
USCS	Unified Soil Classification System
RWG	Technical guide for backfilling and capping layers - LCPC-SETRA
DWG	Technical guide for soil treatment with lime and/or hydraulic binders

Table 2

A.1.3.2 Symbols

We refer in this respect to the list of symbols mentioned in the European standard "Earthworks". This list has the advantage of being sufficiently comprehensive for the presentations of the Manual and of being compatible with what is used worldwide (particularly American standards).
These symbols are presented in Tables 3 to 6 below.

Reference European standard "Earthworks"

❖ Parameter symbols (1)

av	air percentage of voids	dimensionless
c'	effective cohesion	kPa
CC	curvature coefficient	dimensionless
CCaCO3	calcium carbonate content	dimensionless (%)
COM	organic matter content	dimensionless (%)
CU	uniformity coefficient	dimensionless
Csalt	soluble salt content	dimensionless (%)
Cx	mass percentage of particles of dimension less than x (mm) C2µm, C63µm, C80µm, C2mm, …	dimensionless (%)
Dmax	maximum dimension of the largest elements contained in the soil	mm
DPr	compaction or degree of compaction $\rho_d / \rho d max = \gamma_d / \gamma_{dmax}$	dimensionless
Dx	particle size in relation to which x % are finer	mm
e	void index	dimensionless
E	modulus of elasticity	MPa
Ec	modulus of elasticity in compression	MPa
Eit	modulus of elasticity in indirect tension	MPa
And	modulus of elasticity in direct traction	MPa
EV1 (M1)	EV1 plate test module	MPa
EV2 (M2)	EV2 plate test module	MPa
Gv	volume swelling	dimensionless
LA(1) or CLA	Los Angeles coefficient (1) used in test standard EN 1097-2	dimensionless
Ls	linear inflation amplitude (CBR mold)	mm
MDE(2) or CMDE	Micro-Deval coefficient (2) used in test standard EN 1097-1	dimensionless

Table 3

❖ Parameter symbols (2)

n	Porosity	dimensionless
na	air content volume = air volume/total volume	dimensionless
P	degree of spraying	dimensionless
R	compressive or tensile strength	MPa
Rc	compressive strength	MPa
Ri	compressive or tensile strength after immersion in water	MPa
Rit	indirect tensile strength	MPa
Rt	tensile strength	MPa
Sr.	degree of saturation	dimensionless
VBS	methylene blue value (fraction 0/50 mm)	g/100 g
Vp	speed of compression waves	m/s
Vs	shear wave velocity	m/s
w	water content	dimensionless
wL	liquidity limit	dimensionless (%)
wn	natural water content	dimensionless
wOPM	optimal water content (modified Proctor test)	dimensionless
wOPN	optimal water content (Proctor test)	dimensionless
wP	plastic limit	dimensionless (%)
wS	withdrawal limit	dimensionless (%)
x % ρdmaxOPN	fraction x % of the maximum dry density of the Proctor reference curve	Mg/m3

Table 4

❖ Parameter symbols (3)

$\varepsilon coll$	linear deformation (odometer)	dimensionless
εsw or εg	linear swelling deformation	dimensionless
εvsw or εvg	volume swelling deformation	dimensionless
γ	bulk density	kN/m3
γ_b	bulk density	kN/m3
γ_d	dry bulk density	kN/m3
γ_{dn}	dry bulk density in place	kN/m3
γ dmaxOPM	maximum dry bulk density at water content optimal in the modified Proctor test (OPM)	kN/m3
γ dmaxOPN	maximum dry bulk density at water content optimal in the Proctor test (OPN)	kN/m3
ν	Fish Coefficient	dimensionless
φ'	Internal friction angle	degree
ρ	Density mass	Mg/m3
ρb	Apparent density	Mg/m3
ρd	Dry density mass	Mg/m3
$\rho dmaxOPM$	maximum dry density at water content optimal in the modified Proctor test (OPM)	Mg/m3
$\rho dmaxOPN$	maximum dry density at water content optimal in the Proctor test (OPN)	Mg/m3
ρdn	dry density in place	Mg/m3

Table 5

❖ **Clues Symbols**

Ic	consistency index	dimensionless
ICBR	California Bearing Index CBR Index	dimensionless
ICBRi	CBR index after immersion	dimensionless
ID	density index	dimensionless
IDG	degradability coefficient	dimensionless
IFR	fragmentability coefficient	dimensionless
IFS	sand friability coefficient	dimensionless
IIPI	Immediate supporting index IPI Index	dimensionless
Im	Thornwaithe Index	dimensionless
IMCV	humidity condition value index	dimensionless
IP	plasticity index	dimensionless (%)
Ir	resistance ratio after immersion (Ri/R)	dimensionless
Is50	compressive strength index under load one-time	MPa

Table 6

A 1.3.1 Terminology

❖ **Reference PIARC Technical Report (2013 - 2012R37FR)**

Marginal material / Definition

Material that does not fully comply with the specifications in force in a country or region for normal road materials, but which can be used successfully, either under special conditions made possible by climatic conditions or by recent advances in road technology, or after undergoing special treatment.

❖ **Reference European standard "Earthworks"**

Among terms and definitions presented in the article III “General information on the European Standard Earthworks”, some of them are prosed to be integrated into the PIARC Dictionnary.

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Civil engineering processes that modify the geometry of the ground surface by creating stable and durable earth-structures

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Moisture content
Ratio between the weight of water contained in a particular sample and the weight of dry soil

Trafficability
Ability of the surface of a material to withstand the passage of earth-moving machinery

Capping layer
Specific transition layer, located in the upper zone of the earthworks, placed under the superstructure. The capping layer is an integral part of the earthwork

Superstructure
Civil engineering structure installed on the earth-structure (example of superstructures: pavement, railway track, buildings, gantries, etc.)

World Road Association (PIARC)

La Grande Arche, Paroi Sud, 5e étage, F-92055 La Défense cedex

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