



Implementation of Design during Execution & Service Life

Guidelines for the application of the 2nd generation of Eurocode 7: Geotechnical design

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Abstract

EN 1997, also known as Eurocode 7, is the European standard for geotechnical design that provides the basis for the geotechnical aspects of building and civil engineering.

The 2nd generation of EN1997 places a requirement on the designer to specifically address the implementation of their design as a part of the overall design process. The code lays out a series of plans which are to be produced by the designer to be used alongside the requirements of the execution standards.

This guideline aims to provide the user with advice on the content to consider for these plans, with examples for different geotechnical structures. The guide indicates methods to align the design code requirements with the practical considerations of the execution phase of the project.

EN1997 requires that the designer considers how the structure is to be checked during the service life and maintenance stage after actual construction is complete. The examples in this guide also cover how these requirements can be built into the plans that are specified as design output.

Foreword

JRC Foreword

The construction ecosystem is of strategic importance to the European Union (EU), as it delivers the buildings and infrastructures needed by the rest of the economy and society, having a direct impact on the safety of persons and the quality of citizens' life. The construction ecosystem includes activities carried out during the whole lifecycle of buildings and infrastructures, namely design, construction, maintenance, refurbishment and demolition. The industrial construction ecosystem employs around 25 million people in the EU and provides an added value of EUR 1 158 billion (9.6% of the EU total)^{1,2,3}.

The construction ecosystem is a key element for the implementation of the European Single Market and many other important EU strategies and initiatives. The European Green Deal ([COM\(2019\) 640 final](#)) aims to achieve climate neutrality for Europe by 2050, and relies on numerous initiatives, noteworthy:

- the New Circular Economy Action Plan ([COM\(2020\) 98 final](#)) and the New Industrial Strategy for Europe ([COM\(2020\) 102 final](#)) intending to accelerate the transition of the EU industry to a sustainable model based on the principles of circular economy;
- the revision ([COM\(2022\) 144 final](#)) of the Construction Products Regulation ([Regulation \(EU\) No 305/2011](#)) aiming to enable the construction ecosystem's contribution to meeting climate and sustainability goals and embrace the digital transformation of the built environment;
- the New EU Strategy on Adaptation to Climate Change ([COM \(2021\) 82 final](#)) supported by the recent Commission Communication on managing climate risks ([COM\(2024\) 91 final](#)) that reinforces the need to address climate change concerns to guarantee resilience and sustainability of built structures and infrastructures and to ensure regular science-based risk assessments;
- the first European Climate Risk Assessment ([EUCRA](#)) report which highlights the importance of EU policies for the built environment, including updating construction standards and related European datasets.

Furthermore and recognizing that the EU's ambitions towards a climate neutral, resilient and circular economy cannot be delivered without leveraging the European standardization system, the European Commission presented a new Standardization Strategy ([COM\(2022\) 31 final](#)). The strategy spots standards as *"the silent foundation of the EU Single Market and global competitiveness"*.

The EU has put in place a comprehensive legislative and regulatory framework for the construction sector, including European standards (EN). Within this framework, the [Eurocodes](#) are a series of 10 European standards, EN 1990 to EN 1999, providing common technical rules for the design of buildings and other civil engineering works. In fact, the Commission Communication on managing

¹ Commission staff working document: Scenarios for a transition pathway for a resilient, greener and more digital construction ecosystem (<https://ec.europa.eu/docsroom/documents/47996>)

² Council of the EU, Press release 30 June 2023, <https://www.consilium.europa.eu/en/press/press-releases/2023/06/30/council-adopts-position-on-the-construction-products-regulation/>

³ Transition Pathway For Construction, European Commission, DG GROW, <https://ec.europa.eu/docsroom/documents/53854>

climate risks directly mentions the Eurocodes, highlighting the role of building and infrastructure standards in integrating climate adaptation and resilience.

The [Commission Recommendation 2003/887/EC](#) on the implementation and use of the Eurocodes for construction works and structural construction products recommends undertaking research to facilitate the integration into the Eurocodes of the latest developments in scientific and technological knowledge. In this context, the so-called second generation of the Eurocodes is under development under Mandate M/515 and expected to be available by 2026. The second generation Eurocodes incorporates improvements to the existing standards and extends their scope by embracing new methods, new materials, and new regulatory and market requirements, including considerations for climate change impact on structural design.

In order to support the implementation of the second generation EN 1997 “Geotechnical Design”, CEN Technical Committee 250/Sub-Committee 7 (TC250/SC7) produced a series of guidelines addressing the most important new aspects in the standard. The series of guidelines contains the following documents:

- Guideline C1 – “Determination of representative values from derived values for verification of limit states with EN 1997”
- Guideline C2 – “Assembling the Ground model and the derived values”
- Guideline C3 – “Reliability-based verification of limit states for geotechnical structures”
- Guideline C4 – “Implementation of design in execution and service life”

Within the framework of Administrative Arrangements between the European Commission’s Joint Research Centre (JRC) and DG GROW on support to policies and standards for the construction ecosystem, JRC is engaged in activities facilitating the implementation and practical use of the second generation Eurocodes. In this context, the guidelines by TC250/SC7 are published as JRC technical reports, part of the series “*Support to the implementation, harmonization and further development of the Eurocodes*”.

We hope that this report will provide a sound and helpful basis for the implementation and use of the second generation EN 1997 “Geotechnical Design” and contribute to training and education of the professionals engaged in geotechnical design, supporting further skills development for individuals' careers and also EU's competitiveness. The report is available to download from the “Eurocodes: Building the future” website (<http://eurocodes.jrc.ec.europa.eu>).

The authors have sought to present useful and consistent information in this report. However, users of the information contained in this report must assess if such information is suitable for their purposes.

Ispra, September 2024

François Augendre, Head of Unit
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SC7 Foreword

With the adoption of the 2nd Generation of EN1997 – Geotechnical design – Member States will need to implement new procedures in many different topics, not considered in the first generation of the Code such as the assessment of Representative values, the Ground Model, the use of Reliability methods and the implementation of design in the execution phase. To facilitate the implementation of EN1997, CEN Technical Committee 250/Sub-Committee 7 (TC250/SC7) therefore decided to produce a suite of Guidelines, one for each of the most relevant new aspects, to help ensure that the objectives of the code writers are reached in practice.

According to Clause 4 of EN1997, Basis of design, the fundamental step to ensure that the prescribed reliability in geotechnical design is reached, is the development of a representative Geotechnical Design Model being the combination of the Ground Model and the set of design values of relevant geotechnical properties needed for verifications.

The first Guideline of the suite addresses the fundamental process of determining design values of geotechnical properties from derived values, obtained from a variety of activities of the ground investigation. Once the representative values of properties, either characteristic (through statistical evaluation) or nominal (cautious estimate), are determined, design values are obtained by applying the partial factors for a design situation.

The process of assembling the Ground Model is addressed in the second Guideline, where the importance of the progressive upgrading of the Model with an increase of knowledge of the ground within the Zone of Influence of the specific structure is highlighted. The concept of the Zone of Influence in the second generation of EN1997 has been widened so that environmental and seismic aspects have become more central in planning the Ground Investigation and processing the results.

A significant novel aspect is the use of EN1997 in combination with reliability-based methods. This is likely to lead to a very important evolution of safety assessments in geotechnical design in the coming years. EN1997 like other Eurocodes is fundamentally reliability-based although safety verifications are tied to the application of partial factors. However, in the second generation of EN1997, Clause 4 explicitly states that reliability-based design is only one of the options to verify limit states in geotechnical design. As these methods are not usually addressed in most of the teaching programs, it has been decided to dedicate a specific guideline to reliability-based verification of limit states that is consistent with the safety concepts of the Eurocodes. Moreover, the objective of this third Guideline is to provide information for code developers to perform reliability calibration of partial factors given the preparation of National Annexes.

It is well known by geotechnical designers that a great contribution to the reliability of a geotechnical construction relies upon its execution and its real performance. This is why EN1997 now specifically dedicates a full clause in EN 1997-1 to the implementation of design during execution and service life. The fourth Guideline presents measures to ensure that the design is correctly implemented in the different construction phases and how to document the activities carried out to this scope on the construction site. After a general description of the suggested rules and methods, the guideline describes good practice for establishing a Supervision Plan, Inspection Plan, Monitoring Plan and Maintenance Plan, how to establish acceptance criteria and limit values and gives contingency measures that might be utilized when an acceptance criterion/limit value is reached. This is implemented for typical geotechnical constructions such as embankments, bored piles, rigid inclusions, and groundwater control.

The upgrading of EN1997 to the methods of modern Geotechnics was a very difficult task that has been achieved thanks to the strong involvement of many dedicated people from all European

countries. However, this process cannot be considered concluded with the publication of the new Eurocode documents alone and there will be a long route to implementing EN1997 into the engineering practices of the many countries involved.

The involvement of the many members of the Task Group C1 to C4 of SC7, who prepared these Guidelines is very gratefully acknowledged. These Task Groups have performed tremendous work over almost 4 years to compile knowledge and experience in European geotechnical engineering to draft these Guidelines.

It is therefore strongly believed that for the transition from the 1st to the 2nd Generation of EN1997, these Guidelines will be very helpful in clarifying the new concepts and methods. The Guidelines will also provide didactic background material that could not be presented in the Code.

Giuseppe Scarpelli, Coordinator Task Group C1 to C4

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The guideline has been reviewed by members of the management group within SC7.

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1 Introduction

1.1 Context

The design and performance of a geotechnical structure is directly linked to the method of construction, and the quality of the execution. As a result, it is important that the assumptions and requirements of the design are properly communicated through to the execution team, and onwards into the service life of the structure. Further, it should be noted that the expression “designer” does not only address the “classic” design portion by a geotechnical or structural designer, but any party or person that is involved in the preparation of the envisaged construction process – for example, work preparation, scheduling, site manager etc.

The aforementioned “classic” design portion of the process is covered by EN1997, and there are accompanying execution standards for different techniques to cover the construction phase. These documents are complementary but exist in parallel to each other. The new generation of EN1997 now stipulates that the execution process and service life are specifically addressed at the design stage, which requires linking the two sets of documents in a way that was not always previously addressed.

This document is intended to provide guidance alongside, and a link between, the formal CEN design and execution standards.

1.2 Objectives

This document has been written to address specific points identified by the CEN TC250/SC7 management committee as needing further clarification and guidance to allow the users to meet the requirements of the code.

These points are:

- general guidelines on the implementation of the design during execution
- guidelines on good practice for establishing a Supervision Plan, Inspection Plan, Monitoring Plan and Maintenance Plan as required in the next generation code
- guidelines on establishing acceptance criteria and limit values
- guidelines on contingency measures that might be utilized when an acceptance criterion/limit value is reached.

1.3 Target audience

The target audience for this guideline is predominantly:

- Practitioners designing geotechnical structures
- Contractors carrying out the execution of geotechnical structures, to their own design or that of others.

As the design code requirements extend beyond execution and into the service life of the structure, there are aspects that will also be of interest to the final owner/operator.

1.4 Scope

There is a mandatory requirement set out in EN1997-1, cl. 10.1 for the design to include specifications and plans to allow the implementation for the design to be correctly managed during execution and the design service life. The nature of the code means that it cannot include examples or guidance on how this requirement is to be met. This document is intended to help users address the requirements of this design clause.

[EN 1997-1 cl. 10.1: (1) <REQ> The design of a geotechnical structure shall include specifications for supervision, inspection, monitoring, and maintenance to check implementation of the design during execution and design service life.]

These guidelines have been written to be applicable to all scales of geotechnical project, be it GC1 or GC3. As with all geotechnical design, the application of the advice requires judgement to suit specific site ground conditions and cannot cover all situations in detail.

[EN 1997-1 cl. 4.1.2.3 Geotechnical Category]

1.5 Application of this guide

In principle, this guide is applicable to all design phases in a project. Although a successful “Implementation of design” can of course only be proven once execution has started, it is essential to understand that the basis for such is laid from the project beginning, or, vice versa, it is difficult to overcome shortcomings from earlier design stages during detailed design or even execution.

Examples supplied are not exhaustive and engineering judgement will be required to apply them to any specific project, especially in complicated situations (geometry, ground conditions, location, etc).

2 Implementation of design in execution

2.1 General aspects of successful “implementation of design in execution”

The following factors have been identified as key for a specific project:

1. Common understanding of terms (refer to chapter 2.2)
2. Common understanding of project phases (refer to chapter 2.3)
3. Common understanding of roles and responsibilities (refer to chapter 2.4)
4. Common understanding of key design factors and risks (refer to chapter 2.5)
5. Common understanding of effective communication (refer to chapter 2.6)
6. Common understanding of good and transparent documentation (refer to chapter 2.7)

2.2 Definition of terms

The following terms and definitions have been elaborated within this report, above those already supplied within the code. These are for clarification and are not meant to replace the code definitions:

2.2.1 Supervision

Supervision is an act or instance of directing, managing, or oversight and comprises all measures or activities during execution to check and ensure that the construction work is carried out by personnel having appropriate skill and experience and follows the process, including execution methods and construction stages, set by the execution specification.

Note: As a minimum, supervision is conducted by the party executing the respective process (e.g. the Designer supervises the design process, the Contractor supervises the construction process). The responsibilities for any additional supervision activities should be specified by the relevant authorities or, where not specified, agreed for a specific project, by the relevant parties.

(Definition according EN 1997-1 cl. 3.1.9.4 supervision: “measures or activities during execution to check that the construction work follows the process, including execution methods and construction stages, set by the execution specification”.)

2.2.2 Inspection

An inspection is an organized examination or formal evaluation exercise and comprises measures or activities during execution to check the compliance of the execution with the execution specification and the validity of the design assumptions in relation to encountered ground conditions at the site. Inspection is understood to mean checking the material and product properties, ground conditions, dimensions and quality.

Note: As a minimum, inspection is conducted by the party providing the material or product (e.g. the Designer inspects the design report, the Contractor inspects the construction product). The responsibilities for any additional inspection activities should be specified by the relevant authorities or, where not specified, agreed for a specific project, by the relevant parties.

(Definition according EN 1997-1 cl. 3.1.9.5 inspection: “measures or activities during execution to check the compliance of the execution with the execution specification and the validity of the design assumptions in relation to encountered ground conditions at the site”).)

2.2.3 Monitoring

Measuring/observing the behaviour of the ground and/or structure, during execution and / or design service life, to check compliance with the anticipated behaviour defined by a set of threshold values and determined by calculation or engineering judgement.

Note: The responsibilities for monitoring activities should be specified by the relevant authorities or, where not specified, agreed for a specific project, by the relevant parties.

(Definition according EN 1997-1 cl. 3.1.9.6 monitoring: “measuring / observation of the behaviour of the ground and/or structure, to check compliance with the serviceability criteria”).)

2.2.4 Maintenance

Set of activities performed during the service life of the structure so that it fulfils the requirements for reliability.

Note: The responsibilities for maintenance are typically with the owner of the structure, unless specified otherwise by the relevant authorities or agreed for a specific project, by the relevant parties.

(No definition available for maintenance in EN 1997-1).

2.2.5 Execution specification

Set of documentation, typically prepared by several parties, necessary for the execution of a project.

As outlined in EN 1997-1 C4.1, the geotechnical designer’s contribution to the execution specification forms part of the Geotechnical Design Report.

Note: The responsibilities for the contribution to the execution specification, as well as the continuous update and distribution of the content list and revision control, should be specified by the relevant authorities or, where not specified, agreed for a specific project, by the relevant parties.

(Definition according EN 1997-1 cl. 3.1.9.7 execution specification: “set of documents covering all drawings, technical data and requirements necessary for the execution of a particular project

Note: The execution specification is not one document but signifies the total sum of documents required for the execution of the project. It includes the project specification prepared to supplement and qualify the requirements of the European Standards, as well as referring to the national provisions relevant in the place of use.”).

Note: EN 1997-1 allows any format for the execution specification. However, unless there are specific requirements to do it another way, it is recommended to focus on drawings for all design-related information for the execution specification. It is further recommended to set up, continuously update and communicate an overview content list for all elements forming a project’s execution specification, including revision control.

2.2.6 Designer

A designer is one or multiple persons or parties planning a physical structure during a time period before it is erected, by preparing static calculations, drawings, plans, method statements or other contributions to the execution specification. The geotechnical designer, in this report, is the person(s) or party preparing the geotechnical design calculations for a project.

Note: “Designer” must therefore not be understood automatically as “the geotechnical / structural designer” (conducting the geotechnical or structural design calculations) solely. It can also be the scheduler, the work preparer, or anybody else providing input to the execution specification.

2.3 Definition of project phases

A project typically follows a couple of phases from the initial project idea until its decommissioning.

The organisation of any given project is specific. It depends, amongst other things, on influences such as the Client requirements and national legislation.

In order to understand the development of all design-related as well as execution-related documentation and the dependencies during these phases, it is firstly necessary to define the wording of these phases.

For this report, the UK-based RIBA stages are used as a basis, while other countries use other phases, e.g. in Germany the HOAI-phases. Table 1 gives an international comparison of these stages:

(RIBA = Royal Institute of British Architects, see <https://www.architecture.com> and HOAI = Honorarordnung für Architekten und Ingenieure, see <https://www.hoai.de>)

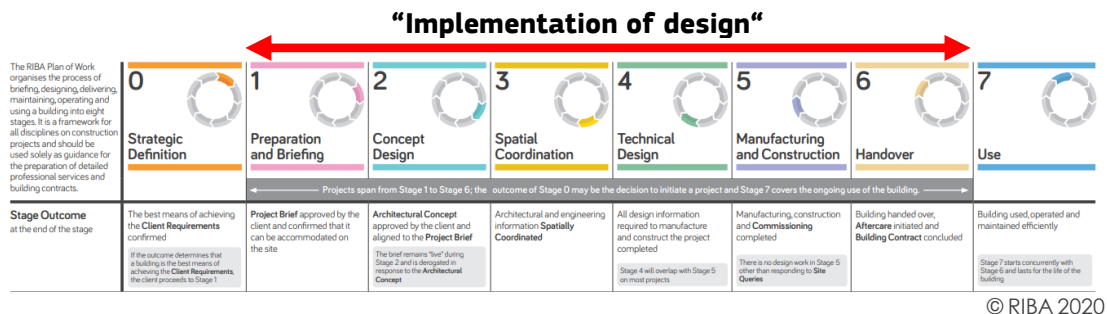
Table 1. Comparison of international plans of work

	Pre-Design		Design					Construction	Handover	In Use	End of Life
RIBA (UK)	0	1	2		3	4		5	6	7	
	Strategic Definition	Preparation and Brief	Concept Design	NOT USED	Developed Design	Technical Design		Construction	Handover & Close Out	In Use	NOT USED
ACE (Europe)	0	1	2.1	2.2	2.3	2.4		3		4	5
	Initiative	Initiation	Concept Design	Preliminary Design	Developed Design	Detailed Design		Construction	NOT USED	Building Use	End of Life
AIA (USA)			-		-	-		-			
	NOT USED	NOT USED	Schematic design	NOT USED	Design Development	Construction Documents		Construction	NOT USED	NOT USED	NOT USED
APM (Global)	0	1	2		3	4		5	6	7	
	Strategy	Outcome Definition	Feasibility	NOT USED	Concept Design	Detailed Design		Delivery	Project Close	Benefits Realisation	NOT USED
Spain			-			-		-	-		
	NOT USED	NOT USED	Proyecto Basico	NOT USED	NOT USED	Proyecto de Ejecucion		Direccion de Obra	Final de Obra	NOT USED	NOT USED
NATSPEC (Aus)		-	-	-	-	-		-		-	
	NOT USED	Establishment	Concept Design	Schematic Design	Design Development	Contract Documentati on		Construction	NOT USED	Facility Manageme nt	NOT USED
NZCIC (NZ)		-	-	-	-	-		-		-	
	NOT USED	Pre-Design	Concept Design	Preliminary Design	Developed Design	Detailed Design		Construct	NOT USED	Operate	NOT USED
HOAI (DE)	1	2	3	4	5	6		8	NOT USED	9	
	Grundlagenermittlung Basic determination	Vorplanung Pre- Design	Entwurfsplanung g Concept Design	Genehmigung splanung							
South Africa		1	2	3		4		5			
	NOT USED	NOT USED	AGR Stage	Stage P	Tender Stage	Construction Documents		Construction	NOT USED	NOT USED	NOT USED

Source: Developed by the Authors

The measures discussed under EN 1997-1 cl. 10 Implementation of design can have relevance from the start of RIBA stage 1 (starting with the initial site surveys) until the end of RIBA stage 7 (with the end of any maintenance measures for the structure).

Figure 1. RIBA Stages and potential relevance of EN1997-1 cl.10.1 Implementation of Design



Source: RIBA Plan of Work 2020

In Figure 2, the project phasing sequence including the preparation of documents for a “typical” project is shown.

What becomes obvious is that specific activities are repeated, and the scope and depth of investigation becomes more and more detailed with the progression of the project through the project phases.

It should be considered a standard procedure that at the transition from one phase to the other, all activities from the previous phase are revised (cross-discipline) for consistency. This is also convenient because parties to the contract often join or leave a project at these transition points.

2.4 Roles and responsibilities

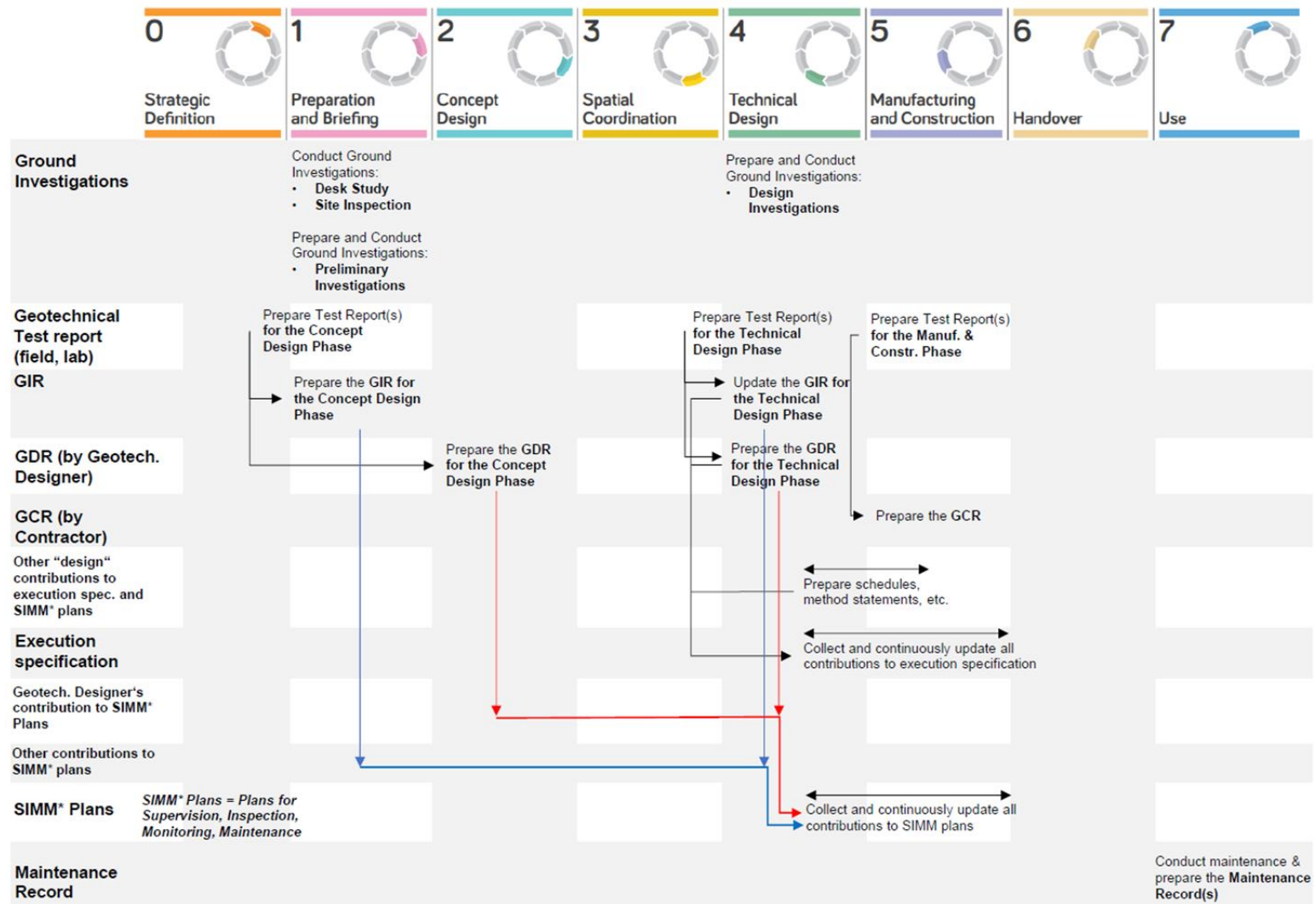
2.4.1 Roles and responsibilities: General

It is not in the remit of EN1997 to define contractual responsibilities, however it is essential that all roles and responsibilities are identified in a project, and that all parties and individuals involved have the same understanding of those and of their own areas of responsibility.

This is especially important when roles, responsibilities or parties change during the project phases (scheduled or unscheduled) – in that case, it is of utmost importance to define:

- which roles, responsibilities or parties change or leave the project team
- what is the degree of completion / fulfilment at the key date of change or handover
- by whom and at which key date the affected roles or responsibilities are taken over
- when and how work results are handed over, and how this is documented
- if and to which extent work results which are taken over remain within the responsibility of the preceding party/person or the follow-on party/person, and
- if and to which extent work results require a (documented) check by the party/person handing over and or the party/person taking over.

Figure 2. Project phasing sequence including the preparation of documents for a “typical” project



Source: Developed by the Authors

2.4.2 Roles and responsibilities: typical roles

The following roles are considered “typical” in this report:

- The Project Owner – usually one party (or consortium of several parties acting as one for the project) that typically orders, pays and finally owns the project
- The Architect - usually one party (or consortium of several parties acting as one for the project) that define the position, the inner geometries and main properties of the Project, typically having a contract with the Project Owner
- The Contractor(s) – one or several parties responsible for the execution of (parts of) the works, having a contract with the Project Owner, possibly contracting with own subcontractors for portions of their work.
- The Designer(s) – one or several parties responsible for the design of (parts of) the works, having a contract with the Project Owner or one of the Contractors. Note that in the sense of 2.2.6. the Contractor or other parties can also play a role as a “designer” for a project.
- The Subcontractor(s) - one or several parties responsible for specific specialist works e.g. site investigations, enabling or demolition works.

2.4.3 Checklist proposal

As outlined in the previous subchapters, roles and responsibilities should be identified as project-specific, unless defined by the relevant authorities. The attached Checklist can help to get and keep an overview over the roles and responsibilities applicable in a specific project.

Figure 3. Checklist for Implementation of Design related to project stage

Checklist for Implementation of design – All stages overview

		My Project:			Responsible	Completion Date	Comment
RIBA Stage	Activity	GC1	GC2	GC3			
Design	0-Strategic Definition						
	1.1 & 1.2. Conduct Ground Investigations: - Desk Study - Site Inspection	REQ	REQ	REQ			
	1.3 Prepare and Conduct Ground Investigations: - Preliminary Investigations	REQ	REQ	REQ			
	1-Preparation & Briefing						
	1.4 Prepare the GIR for the Concept Design Phase		REQ	REQ			
	2-Concept Design						
	2.1 Prepare the GDR for the Concept Design Phase	REQ*	REQ*	REQ*			
	3-Spatial Coordination						
	4.1 Prepare and Conduct Ground Investigations: - Design investigations		REQ**	REQ**			
	4.2 Update the GIR for the Technical Design Phase						
Construction	4-Technical Design						
	4.3 Prepare the GDR for the Technical Design Phase	REQ****	REQ****	REQ****			
	5-Manufacturing & Construction						
Operating	5.1 Execute project and setup Geotechnical Construction Record (GCR)	REQ	REQ	REQ			
	6-Handover						
Operating							
	7-Use						
	7.1 Conduct maintenance	REQ***	REQ***	REQ***			

REQ* means is a requirement for all design phases and execution, refer to EC7-1 §12.1.(4)

REQ** means is a requirement acc. EC7-2 §5.1 (8) applies

REQ*** means is a requirement when maintenance activities are described in the GDR, refer to EC7-1 §10.5 also

REQ**** refer to EC7-1 §12.3.1. (1)

Checklist for Implementation of design

My Project:					
RIBA Stage	Activity	Reference / Comment	Responsible	Completion Date	Comment
Design	1.1 Conduct Ground Investigations: - Desk Study	EC7-2 §5.2.1 (1), 5.2.2 EC7-2 Annex C "Desk study and site inspection"			
	1.1.1 Assume GCC3 as a starting point	EC7-2 Table 5.1 footnote a			
	1.1.2 Determine the preliminary Zol prior to ground investigations	EC7-1 §4.1.2.1 (2)			
	1.1.3 Establish the preliminary Geotechnical Complexity Class (GCC)	EC7-1 §4.1.2.2 (2)			
	1.2 Conduct Ground Investigations: - Site Inspection	EC7-2 §5.2.2 (1), 5.2.3 EC7-2 Annex C "Desk study and site inspection"			
	1.3 Prepare and Conduct Ground Investigations: - Preliminary Investigations (not necessarily for GC1)	Extent of GI according EC7-2 table 5.1 and EC7-2 §5.2			
	1.3.1 Define a preliminary Consequence Class (CC)	EC7-1 §4.1.2.3, EC-0 §4.3			
	1.3.2 Define a preliminary Geotechnical Category (GC)	EC7-1 §4.1.2.3			
	1.3.3 Define type and extent of Preliminary investigations	EC7-2 §5.2.3, Annex D "Information to be obtained from ground investigation"			
	1.3.4 Conduct Preliminary investigations	EC7-2 §5.2.4			
	1.3.5 Undertake monitoring during ground investigation, to obtain data of the ground behaviour	EC7-1 §10.4 (1)			
	1.4 Prepare the GIR for the Concept Design Phase	EC7-1 §12.2, EC7-2 §13.1, Annex A "Ground Investigation Report", with referencing to: - Field reports; - laboratory test reports; - field investigation and monitoring reports; - desk studies; and - geological and hydrogeological studies.			
	1.4.1 Write the GIR under following considerations	EC7-2 §13.1, EC7-1 §12.1			
	1.4.2 Review and update the Zol based on EC7-1 §4.1.2.1: ground investigations	EC7-1 §4.1.2.1			
	1.4.3 Review and update the GCC based on ground investigations	EC7-1 §4.1.2.2 (4)			
	1.4.4 Review and update the CC if necessary	EC7-1 §4.1.3			
	1.4.5 Review and update the GC if necessary	EC7-1 §4.1.2.3			
	1.4.6 Establish specifications for supervision, inspection, monitoring, and maintenance to check implementation of the design during execution and design service life.	EC7-1 §10.1			
	1.4.7 Document the Ground Model and derive ground properties for all geotechnical units in the Geotechnical Investigation Report (GIR). Extent of GI according EC7-2 table 5.1	EC7-2 §4.1, §13.1			
	1-Preparation & Briefing				

RIBA Stage	Activity	Reference / Comment	Responsible	Completion Date	Comment
Design	2.1 Prepare the GDR for the Concept Design Phase	EC7-1 §8.4			
	2.1.1 Review and validate the GIR (not necessarily for GC1)	EC7-1 §6.4.2.4, §4.2 (2)			
	2.1.2 Establish the Geotechnical Design Model	EC7-1 §12.3.2			
	2.1.3 Conduct the design for the GDR for Preliminary Design Phase	EC7-1 §12.3.1 (1)			
	2.1.4 Determine the extents of the zone of influence from the extent of any transient or persistent changes in the representative groundwater or piezometric levels	EC7-1 §4.1.2.1 (4)			
	2.1.5 Update and establish specifications for supervision, inspection, monitoring, and maintenance to check implementation of the design during execution and design service life.	EC7-1 §10.1			
	2-Concept Design				
	3-Spatial Coordination				

RIBA Stage	Activity	Reference / Comment	Responsible	Completion Date	Comment
Design	4.1 Prepare and Conduct Ground Investigations: - Design investigations				
	4.1.1 Review the preliminary GDR, the GCC, the CC, the GC, the Zol, and define type and extent of Design Investigations investigations	EC7-2 §5.2.3			
	4.1.2 Conduct Design investigations	EC7-1 §10.4 (1)			
	4.1.3 Undertake monitoring during ground investigation, to obtain data of the ground behaviour	EC7-1 §12.2, EC7-2 §13.1, Annex A "Ground Investigation Report", with referencing to: - Field reports; - laboratory test reports; - field investigation and monitoring reports; - desk studies; and - geological and hydrogeological studies.			
	4.2 Update the GIR for the Detailed Design Phase	EC7-2 §13.1 (1)			
	4.2.1 Review and update the GIR, under consideration of the Design Investigation results, from Preliminary Design Phase to receive the GIR for Detailed Design Phase	EC7-1 §6.4.1.2.1 (3), 4.1.2.2 (4), 4.1.2.3			
	4.2.2 Review the GCC, the CC, the GC, the Zol (Zone of Influence), and update if necessary	EC7-1 §10.1			
	4.2.3 Review and update specifications for supervision, inspection, monitoring, and maintenance to check implementation of the design during execution and design service life.	EC7-1 §8.4			
	4.3 Prepare the GDR for the Detailed Design Phase	EC7-1 §8.4			
	4.3.1 Review the GIR	EC7-1 §6.4.1.2.1 (3), 4.1.2.2 (4), 4.1.2.3			
	4.3.2 Review the GCC, the CC, the GC, the Zol, and update if necessary	EC7-1 §10.4 (1)			
	4.3.3 Conduct the design for the GDR for Detailed Design Phase	EC7-1 §10.1			
	4.3.4 Update specifications for supervision, inspection, monitoring, and maintenance to check implementation of the design during execution and design service life.	EC7-1 §8.4.1, EC7-1 §10.2			
	4.3.5 Setup Supervision Plan	EC7-1 §8.4.1, EC7-1 §10.3			
	4.3.6 Setup Inspection Plan	EC7-1 §8.4.1, EC7-1 §10.4			
	4.3.7 Setup Monitoring Plan	EC7-1 §8.4.1, EC7-1 §10.5			
	4.3.8 Setup Maintenance Plan	EC7-1 §10.4 (1)			
	4.3.9 Undertake monitoring before execution, to establish reference conditions	EC7-1 §3.1.9.7			
	4.4 Prepare Execution Specification				
	4.4.1 Prepare and compile execution specification with, as applicable:				
	4.4.1.1 Method Statements				
	4.4.1.2 Material specifications				
	4.4.1.3 Workshop drawings				
	4.4.1.4 Schedules				
	4.4.1.5 Drawings				
	4.4.1.6 Work preparation				
	4.4.1.7 Temporary Works considerations				
	4.4.1.8 Other: ...				
	4-Technical Design				

	RIBA Stage	Activity	Reference / Comment	Responsible	Completion Date	Comment
Construction	5-Manufacturing & Construction 6-Handover	5.1 Execute the project and setup the Geotechnical Construction Record (GCR)	EC7-1 B5.1.			
		5.1.1. Conduct Supervision according Plan	EC7-1 §10.2			
		5.1.2. Conduct Inspection according Plan	EC7-1 §10.3			
		5.1.3. Conduct self-inspection	EC-0 §87(3)			
		5.1.4. Conduct Monitoring according Plan	EC7-1 §10.4			
		5.1.5. Review the GCR and GC and adapt if applicable	EC7-1 §4.1.2.2., §4.1.2.3.			
		5.1.6. Review results of supervision, inspection, and monitoring	EC7-1 §10.1			
		5.1.7. Setup Construction Record GCR	EC7-1 B5.1			
Operating	7-Use	7.1 Conduct maintenance				
		7.1.1. Undertake post-execution monitoring to evaluate the long-term performance of the structure	EC7-1 §10.4 (1)			
		7.1.2. Undertake maintenance according Maintenance Plan	EC7-1 §10.5			

Source: Developed by the Authors

2.5 Key design factors and risks

In the process of design and its implementation at the construction stage, some of the obtained or assumed information can have a critical role for successful execution and ensuring the specified level of reliability. Such key design factors, as well as all design assumptions, should be presented in a transparent way, allowing for independent review of the project as well as for comparison with real conditions encountered on the site.

Successful implementation of design in execution requires the Contractor, potentially lacking the relevant (geotechnical) design knowledge, to be able to judge whether they are still working within the assumptions of the design and when falling outside of them. Early identification of potential problems is the most reliable way to ensure timely reaction and implementation of appropriate remediation measures.

However, it is the role of the Designer to assess which design factors are:

- critical,
- highly significant,
- just relevant, or
- not relevant to execution phase.

in the context of designed structure and considered limit states. The Designer should then assess what information is needed to be passed to the execution team, and which items should be controlled through the use of the required plans. At all times clarity of communication and relevance should be the key factors in deciding what information from the design needs to be passed over.

The list below comprises the list of common key design factors that normally need to be considered by the designer in sufficient detail, and if needed, verified at the execution stage.

2.5.1 Code references and tolerances

The documentation prepared for the execution specification of a project must clearly state reference to relevant execution codes, state the allowable tolerances and other important conditions of execution.

Note: When tolerances are considered according to the relevant execution standards, reference to the latter can be considered sufficient.

2.5.2 Soil and rock stratification

Assumption of stratification of soil or rock mass is of importance for all types of geotechnical structures. Therefore, the documentation prepared for execution of the works must show the assumed soil / rock stratification, typically in cross sections, and preferably in relation to the designed structural elements or other relevant information (e.g. planned excavation levels).

Note: Those assumptions are commonly presented in the ground model and developed further in the geotechnical design model, but basic information should also appear in the execution drawings.

Where variation in stratification may significantly affect the expected behaviour of a geotechnical structure, the uncertainty in the design assumptions should be carefully considered and emphasized. For highly complex ground conditions and geotechnical structures, development of a 3D ground model might be advisable.

Note: As an example, a remark “grout body of anchor to be fully embedded in sand layer” clarifies that potentially the free anchor length may need to be extended to match actual conditions encountered.

2.5.3 Soil and rock parameters

Geotechnical properties, parameters and characteristic of a soil or a rock mass are commonly considered as the main design assumptions. The geotechnical designer documents the considered geotechnical properties in the defined geotechnical design model. Where appropriate, e.g. for refill or compaction areas, target values for such parameters should be specified on the execution drawings. It is generally advised to also specify expected ranges of variations of the most significant parameters, at least in qualitative manner.

Note: Uncertainty behind the adopted values of ground properties can be often as important as the adopted design values themselves. It is a good practice to inform the execution team of what variation from the baseline assumption is still considered as acceptable by the designer.

2.5.4 Groundwater and assumed groundwater lowering levels

The consideration of groundwater should include not only its current levels, but also how they may (or shall) change in the process of construction or how they might vary with time and seasonal variations. Again, the documentation prepared for execution of the works must show the groundwater levels and possible variations, typically in cross sections.

Note: This is especially important for geotechnical structures at waterfronts and in marine environments. Potential impact of climate change should also be considered.

2.5.5 Adjacent assets, structures and utilities

When adjacent structures are located within the zone of influence, the effect of the new structure on these existing ones should be investigated and evaluated.

Assumed geometries of adjacent structures should be shown on the execution drawings and allowable serviceability limits (e.g. settlement, inclination, noise, vibration) should be defined, as applicable.

2.5.6 Contamination of soils and water

In addition to important environmental aspects of possible contamination of the soils and water at the site, the presence of contaminants usually is a key design factor in terms of durability of structural elements and materials (e.g. steel, concrete).

Note: Durability of a structure in long-term conditions might be highly dependent on aggressiveness of the environment. Design for durability is as important as verification of other limit states.

2.5.7 Permanent and temporary traffic loads assumed

In addition to any permanent loads affecting the behaviour of the structure, any live loads resulting from traffic (e.g. roads, trains, trams) or construction activities (e.g. construction machinery, cranes) should be considered as a key design factor and must therefore be defined in the execution documentation.

Possible load restrictions and exclusion zones should also be clearly stated and included in the maintenance plan.

Note: Ideally, it should be specified for what kind of traffic the load is representative (e.g. allowable weight of construction machinery). Simple presentation of the surcharge adopted in the design might not be sufficiently informative for the contractor and people working at the site.

2.5.8 Design lifetime, construction stages and their assumed maximum durations

In geotechnical engineering, many phenomena are time-dependent in nature. This imposes some restrictions on how some design assumptions should be made in the context of design lifetime of the structure. Furthermore, the order and duration of construction stages will often be important and they should be specified by the Designer when relevant.

Note: When some level of degradation can be expected (e.g. corrosion of a sheet pile wall) over the design lifetime, such scenario should be included in the design analysis.

2.6 Effective communication and documentation

An effective and transparent communication between the project parties, as well as a good documentation system, and management of design, design interfaces, communication, etc., is key for project success.

Therefore, “communication rules and lines” should be agreed and documented such that new parties or persons joining the project can find their way.

Generally, communication should be conducted pro-actively from all parties, i.e. there is an obligation to both fetch and to bring information.

The following sections highlight recommendations for how this should be related to the “Implementation of Design”.

2.6.1 Installation of regular communication lines

It is recommended that all projects:

- Setup and maintain an organizational chart with a contact list including roles and responsibilities.

- Setup and maintain a task list with due dates and responsibilities.
- Setup and continuously update the content list of the execution specification.

Additionally, for GC2 and GC3 projects:

- Setup regular meetings, e.g. on a weekly basis. Such meetings could also be the place to announce and briefly discuss the content and extent of any upcoming document revisions.
- Notes should be taken from the meetings and action lists updated and regularly reviewed. A person to take these notes and manage the action lists shall be clearly identified at the outset.
- Document and interface management must be defined from project inception, with clear guidelines on how to deal with revisions and distribution of documents.
- Define a “core team” from the various parties involved which discusses progress and important issues in short regular intervals and then forwards important information internally within their party. This core team can also play an important role for the handling of errors and omissions detected during the project.
- Setup a “Design Handover Meeting” between all parties between design stages or at the transition from design to execution.
 - The first involved party then wraps up the basic conditions, parameters and design developments and decisions and explains their contribution to the execution specification. It should be highlighted by the designers both what has been done by them, and what has NOT been done by them, and what the expectations are regarding content and timeline of contributions from other parties.
 - Similarly, the second party / parties should describe their understanding of their project participation, interfaces to other parties, as well as their contribution of content and timeline to the execution specification.
- The installation of a design coordination person or even design coordination group has been proven to be beneficial.

Note: The design coordinator’s task is to make sure that quality, completeness (including interfaces) and in-time availability of design comply with the project requirements. Typically, regularly scheduled meetings with notes and follow-ups form the basis of such design coordination.

2.6.2 Interface coordination

Interface coordination between any parties and / or stakeholders involved can form an essential part of the design coordinator’s work (a separate interface manager may be appropriate for larger projects with complex interfaces).

Note: Interface agreements should be considered as a form of communication and therefore should follow the same communication rules (transparency, documentation).

2.6.3 Dealing with errors and omissions

In case of errors, omissions, or the like, it is of special importance to inform all related parties as soon as possible and thoroughly, in order to then define the extent / the limits of such defects and immediately define responsibilities and timelines of associated updates of design and execution of the works.

Note: The “core team” as mentioned in bullet point “Installation of regular communication lines” above could be first point of contact for such cases.

2.6.4 Dealing with change requests

In the event of changes, a change request shall be raised to notify relevant stakeholders of the affected scope of work. Discussion on the change shall be reviewed, discussed, and agreed upon between the design and execution teams. During this process, the effects on scope, responsibilities, budget, and timeline shall be defined and agreed upon. (a separate change control team may be appropriate for larger projects).

Note: The changes should be properly documented and followed during the execution phase. The design coordinator should ensure that the approved changes are complied with through progressive meetings.

2.6.5 Design quality

The execution relies principally on drawings and model representations (including 3D BIM models), and less on written information such as statements, reports etc. Ideally it should be the aim to collect all information required for the execution of the works on a set of drawings solely. This decreases the chance that an important piece of information will be omitted during the construction.

Note: Where this document refers to “drawings” these can be replaced by digital data in 3D models etc. In such case the ability to locate and retrieve the required information becomes even more critical.

The design should be of good quality, this applies in particular to the drawings produced for execution. As already addressed in chapter 2.5 of this report, such drawings can and should comprise information about the Designer’s assumptions and decisions in a way that it can be cross-checked directly on site, without the need for excessive processing and interpretation of the acquired information. Examples are:

- Assumed temporary and permanent groundwater levels;
- Assumed stratigraphy and main parameters of soils;
- Assumed construction staging;
- Assumed traffic loads during construction;
- Assumed maximum design loadings;
- Defined exclusion zones;
- Defined threshold values for monitoring;
- Information about utilities and structures in the vicinity of the works;
- Extent of “Zone of influence”;
- Assumed GCC, GC, CC;
- Assumed tolerances;
- Agreed interfaces;
- Reference to execution codes.

— Reference to other scope of work not covered within the drawing.

The execution detail should be such that (cost / design) responsibility for undesigned sections is not shifted to other parties, e.g. the Contractor, without their prior agreement. This applies e.g. for temporary slopes. Preferably, all major risks should be eliminated or reduced at the design stage. Ideally, during the design phase, the designer should eliminate and/or reduce the foreseeable risks to as low a level as reasonably practicable (ALARP principle). Any residual risks that need to be passed on to the Contractor during the execution phase should be documented in a risk assessment form. The assessment should include details of the significant risks and what actions have been considered necessary to be taken to control the foreseeable risks. The Contractor should always be informed about these risks with full transparency.

2.7 Further guidance

2.7.1 The use of National Specifications

Numerous national guidance documents are available to assist in the clear presentation of construction information. These include for example:

- The ICE Specification for Piling and Embedded Retaining Walls Third Edition (2017)
- The ICE UK Specification for Ground Investigation Third Edition (2022)
- ZTV-ING “Zusätzliche Technische Vorschriften und Richtlinien für Ingenieurbauwerke, Part 1 Section 2 „Technische Bearbeitung“

2.7.2 Geotechnical Baseline Reports (GBR)

Ground conditions influence every aspect of construction, and unforeseen ground conditions can pose a significant risk to a project. Construction costs are often heavily influenced by the pricing of risk, and the purpose of a GBR is to set the range of expected conditions, and ownership of risk so that for example, the Contractor can reduce their contingency allowances.

GBR statements are therefore not necessarily geotechnical fact but represent an agreed position. The GBR is therefore a contractual document - rather than a design document.

This defines a requirement for Contract documentation to include ground reference conditions prepared for or on behalf of the client.

It is essentially a set of statements about the nature of the ground and groundwater, which define the range of expected ground conditions and establish a basis for applying the contract, where conditions encountered during construction are materially different.

Note: GBRs emerged in the US in the early to mid 90s, but in the UK started being used on major infrastructure projects in the early 2000s. At a similar time to the “The Joint Code of Practice for Risk Management of Tunnel Works in the UK” (2003), a guidance document published by the Association of British Insurers and the British Tunnelling Society to set out best practice for managing risk in tunnelling and underground works.

3 Establishing Plans

3.1 General concepts

3.1.1 Introduction

The aim of having a guide on implementation of the design in executions is to help describe the link between them. As the codes highlight the need to base the design on the quality management system described in them, the implementation of the design in execution is one part of it. In order to ensure the necessary level of reliability, there is a requirement in the code to create a series of documents: inspection plan, supervision plan, monitoring plan and maintenance plan. There is nothing in the code to describe how to form these plans, so these guidelines are intended to be a source of ideas. These plans must be part of the geotechnical design report (GDR) but there are no limitations on how it should be done.

They could be implemented as chapters, or they could be appendices. At the same time, it is possible to merge them together if the specific case requires it. For example, it might be hard to separate supervision and inspection in some cases, in which case it would be practical to merge the two plans. There are also cases when one type of plan may not be applicable, for example monitoring plans where monitoring is not needed and so the plan does not exist. In such cases, the omission of a plan should be justified.

To identify the content of each plan, the definitions of supervision, inspection, monitoring and maintenance are crucial. They are cited and commented on in 2.2.1- 2.2.4 of this document.

The link between design based on EN1997 and the execution is not always clear. It is further complicated by the interaction with the execution standards, which in many cases refer to design aspects. At the same time there are a set of laboratory and field tests standards, the set of standards describing the monitoring requirements, specifications and other documents in between design and execution. The aim of having these plans required by the design codes, is to highlight what is crucial from the design point of view and to ensure it is incorporated properly in the execution and quality checks. There might be parameters, factors, elements on which the design is based, and they need to be checked during execution to confirm / validate the design, and to easily and in a timely manner identify where the execution potentially deviates from the design assumptions.

3.1.2 Links to standards

Table 2 shows standards which are used in more than one specific geotechnical structure. These “general” standards include information about supervision, inspection, monitoring and maintenance. The table is to help in the selection of the appropriate standard content when dealing with one of the four plans.

Table 2. Comparison of international plans of work

Code or Guideline	Supervision	Inspection	Monitoring	Maintenance	General Aspects
EN1990 Basis of structural and geotechnical design		x			x
EN1997-1 Geotechnical design – Part 1: General rules	x	x	x	x	x
EN1997-3 Geotechnical design – Part 3: Geotechnical structures	x	x	x	x	
EN ISO18674-2 Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation. Part 2 Measurement of displacement across a line: extensometers			x		x
EN ISO18674-3 Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation. Part 3 Measurement of displacement across a line: inclinometers			x		x
EN ISO18674-4 Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation. Part 4 Measurement of pore water pressure: piezometers			x		x
EN ISO18674-5 Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation. Part 5 Stress change measurements by total pressure cells (TPC)			x		x

Source: Developed by the Authors

3.1.3 Terms

The definition of terms related to supervision, inspection, monitoring and maintenance is described in points 2.2.1- 2.2.4 where additional comments are to be found.

A particular point to highlight and clarify is the difference between supervision and inspection: – supervision is related to the technological process like performing ground improvement, boring piles, building an embankment, etc., inspection is related to materials and products properties like concrete parameters, geometry etc. Inspection covers also the ground model and ground conditions verification. However, the difference will not always be clear and easy to understand. In such cases the key point is to ensure that the required design aspects are picked up and verified through the plans, rather than overly focussing on which plan the point is to be covered in. According to EN1997-1 and EN1997-3 the specified plans must be prepared but there are not requirements as to whether those must be four independent plans (documents) or if everything can be included in one document or even part of a document. This will depend on the geotechnical structure and the ease of use of the document. To some extent it can also be effected by national practices and guidance documents.

3.2 Case study 1 – Embankment

3.2.1 Introduction

When designing geotechnical structures comprising of slopes, cuttings and embankments there are two main sets of standards that need to be considered together: EN1997 and EN16907. The first one deals with geotechnics, the second one with organization of earthworks projects (including cutting and embankments) and their planning. In both there are references to each other and both contain information that is useful while preparing inspection, supervision and monitoring plans.

Within the zone of influence of the geotechnical structure there are several elements to be looked at: subsoil to the identified depth, nearby structures, other geotechnical structures or slopes, and the cutting or embankment itself.

The aim of this example is to show how to prepare plans for a typical simple embankment with no or very low number of adjacent assets. Soft soils are nowadays also typical ground conditions under this type of structure. The example focuses only on the requirements for embankments, which should be widely known, but at the same time highlights some important aspects in terms of ground model verification and monitoring.

Table 3 shows standards related to each case.

Table 3. Links to specific standards

Code or Guideline	Implementation of design – regulations for				
	Supervision	Inspection	Monitoring	Maintenance	General Aspects
EN16907-1. Earthworks – Part 1: Principles and general rules	x	x	x	x	x
EN16907-2. Earthworks – Part 2: Classification of materials		x			x
EN16907-3. Earthworks – Part 3: Construction procedures	x				x
EN16907-4. Earthworks – Part 4: Soil treatment with lime and/or hydraulic binders	x	x			x
EN16907-5. Earthworks – Part 5: Quality control	x	x			x

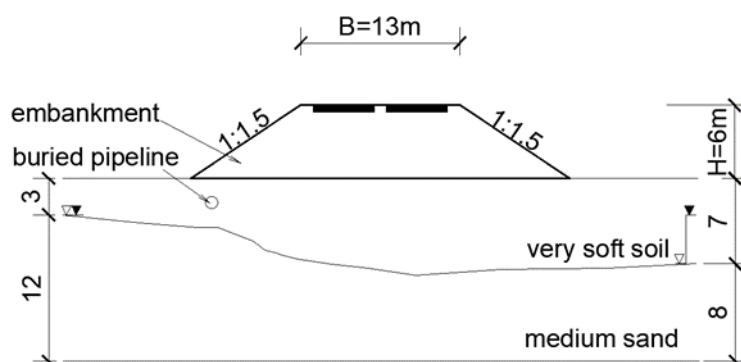
Source: Developed by the Authors

3.2.2 Data

- Soil / rock stratification: very soft clay thickness 3-7m, medium sand till the depth of influence.
- Embankment material parameters assumed: medium sand $c'=0\text{kPa}$, $\varphi'=40^\circ$, $\gamma=18\text{kN/m}^3$, $E=100\text{MPa}$ at 100kPa reference stress.
- Permanent traffic loads assumed as 12kPa, no temporary traffic loads assumed.

- Construction stages: embankment layers 13 x 0.4m + road layers 0.8m. No maximum time constraints; minimum time constraints relating to consolidation of the subsoil.
- Geotechnical category was chosen as GC2.
- Geometry presented in figure 4.

Figure 4. Case study 1 cross section



Source: Developed by the Authors

3.2.3 Summary of plans for supervision, inspection, monitoring and maintenance

The aspects considered in this guide as the most significant and needing to be addressed in the plans are listed in Table 4 and Table 5.

Note: Where specific values are given they are related to this particular case study. Equivalent values for another project need to be evaluated on the specifics of that situation.

Table 4. Information relevant for Supervision and Inspection

Parameter	Determination	Relevant code and clause
Soil group for the first embankment layer (foundation base)	G1 or G2	EN16907-2:2019, cl6
Soil group for the remainder of the embankment layers (core, fill)	S1, S2, G3, G4, S3, S4	EN16907-2:2019, cl6
Other embankment material characteristics	Particle size distribution	EN16907-2:2019, cl8, Table 13 and Annex 1
	Proctor density and optimal water content	
	Water content: $\pm 2\%$ of optimal water content derived from Proctor test	
Friction angle, appropriate modulus of the soil	$\varphi' = 40^\circ$, $E = 100\text{MPa}$ at 100kPa reference stress	EN ISO17892 Parts 5, 9, 10
In situ density testing, stiffness and bearing capacity testing	$D_r = 100\%$, $E_{v1} > 35\text{Mpa}$, $I_p < 2.2$	EN16907-5:2019, cl8 EN16907-1:2019, Annex B

Parameter	Determination	Relevant code and clause
Embankment construction speed	Not faster than one layer per week or as stated during results analysis	Design based
Ground model – indirect evidence	CPT or boring equipment parameters – q_c , f_s and lithology	-

Source: Developed by the Authors

Table 5. Information relevant for Monitoring and Maintenance

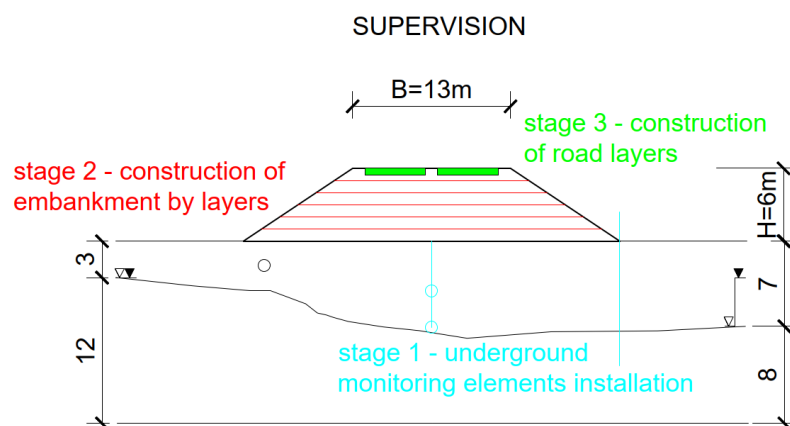
Parameter	Determination	Relevant code and clause
Settlement	< 100mm	Design based
Horizontal deflection	< 20mm	Design based
Pore pressure dissipation	90% of the measured increase	Design based
Signs of slope stability failure	Regular inspections minimum of twice per year (spring, autumn) + after heavy rainfalls	-

Source: Developed by the Authors

3.2.4 Supervision plan - comments

The plan should define construction stages and refer to execution specifications. Examples of the main three stages are shown in figure 5. Depending on the need the plan will include more detailed information about each stage. It is important to be define how each construction stage will interact with other geotechnical structures or objects.

Figure 5. Elements of supervision



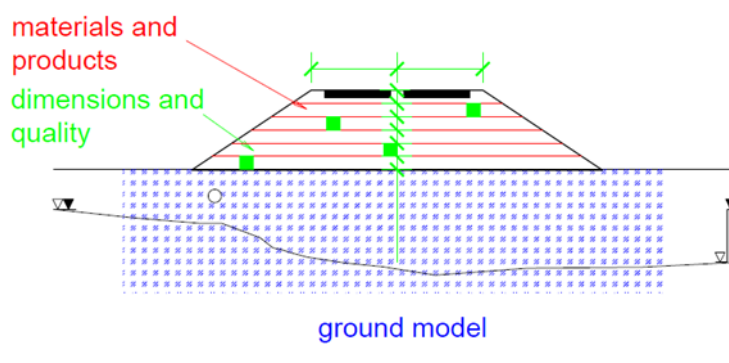
Source: Developed by the Authors

In the described case, the installation of monitoring is a significant factor which affects the embankment construction speed. Clear design-based criteria are to be established as described in the monitoring plan.

3.2.5 Inspection plan – comments

According to the inspection plan definition there are three areas which need to be covered:

Figure 6. Elements of inspection



Source: Developed by the Authors

Material and products properties.

- Material and products shall be used according to the execution specification, project content and relevant codes. In this case these are the materials used for the construction of the embankment. During execution, the embankment will be constructed in layers. Each layer needs to represent appropriate quality – see table 4.
- The embankment material parameters used in the design need to be checked to verify the geotechnical design. In a typical case when the embankment is made of sandy material the key parameters may include: effective friction angle, relative density (used in stability analysis) and appropriate modulus of the soil (used in settlement calculations). In the annexes to EN 16907-2 an exhaustive list of related standards is given for in situ and laboratory testing of those parameters.

Dimensions and quality

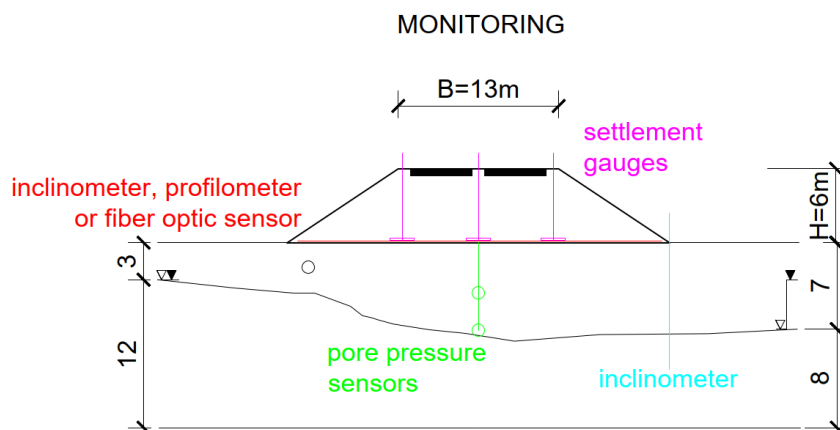
- The plan should contain measures to confirm that the execution is implemented according to the work description and applicable method statement. In EN 16907-5 quality control procedures regarding in situ density testing, stiffness and bearing capacity testing (plate load test and others) are included. Frequency of testing, geometrical tolerances and general information about monitoring are also included there.
- In this example, the very weak soil layer means that the speed of embankment construction may be limited by the soil behaviour. Typically, as a first step it is assumed that layers are constructed no faster than one per week.
- The use of GPS based systems to control the geometry of the structure as it is constructed is an example of how to reduce the potential for human error. Any work done by equipment working with such systems should be checked by traditional methods.
- Quality of the drainage system needs to be checked as well as a part of the embankment structure.

Ground conditions / ground model

- The encountered ground conditions should be checked for compliance with the ground model and geotechnical design model in line with appropriate provisions included in the Inspection Plan.
- Evidence / direct comparisons are preferred – that can be comparison of lithology, soil state, soil type, water table level. Simple visual methods can be used by the site personnel – for example to monitor the water level in a well. In this example some indirect methods are applicable – pressure gauges can be installed using CPT equipment and inclinometers should be installed after borehole execution. Indirect evidence includes parameters of penetration and lithological output from boring, this could be used to identify the base of the soft soils. The geotechnical designer should interpret the records, compare with the available soil investigation and confirm there is no deviation from the design assumptions. Due to the very weak soil layer there is a specific need for pore pressure monitoring (or frequently c_u testing). Acceptance criteria needs to be established based on those values.
- As there are no neighbouring structures and the buried pipeline is quite shallow (2m depth) in this case the zone of influence covers mainly subsoil. As the stronger sandy stratum is relatively shallow, the zone of influence was judged to be at the depth of 12m (7m of soft soils +5m). In other geological conditions (especially when there are only fine grained soils) the zone of influence could depend more on the embankment width – in this case 31m across the base which will lead to a larger depth of zone of influence.

3.2.6 Monitoring plan – comments

Figure 7. Elements of monitoring



Source: Developed by the Authors

- In the case of a simple embankment no monitoring is usually needed; however, in this case two reasons to install monitoring can be found: the presence of the pipeline and the very weak subsoil.
- For the buried pipeline the need for monitoring will depend on the pipeline condition, structure, and deformation limits. A condition assessment might be required in advance of embankment construction, if practical.

- When very weak subsoil is present, then monitoring is necessary. In this example several instruments are used: plate settlement gauges (benchmarks), horizontal inclinometer, vertical inclinometer and pore pressure sensor. The aim is to monitor settlements, horizontal soil movement and pore pressure. Additional information about specific techniques can be found in EN-ISO 18674-1, EN-ISO 18674-2, EN-ISO 18674-3, EN-ISO 18674-4 and EN-ISO 18674-5. (Detailed information can also be found in Dunnicliff (1988).
- To choose the best monitoring technique for settlement the level of expected settlements needs to be estimated and the time when these settlements will occur. It makes no sense to use automatic systems for simple cases where embankment height is not significant as settlements occur only during construction (no creep settlements possible). A precision of 0.1mm is not needed, as a range of 10mm will be sufficient when several cm of movement is expected. Automatic systems are appropriate under buildings of high importance or when the effects of soil displacement can cause significant damage. The information about settlement is however only useful when combined with knowledge of the cause of those settlements. In order to provide sufficient information, it is therefore highly recommended to measure the embankment geometry and soil relative density to estimate the load.
- In the case of vertical inclinometers it is very important to have a benchmark on the top to have a result in the form of absolute displacement. Without the benchmark the measurement will give only relative displacement which can lead to underestimation of displacement or wrong deformation form. This should be defined in the monitoring plan.
- For long term monitoring ABS or similar especially designed casings are required, however for temporary monitoring steel profiles can be used. Steel cannot be used for long term because of its tendency to rust which can cause blocking of inclinometer wheels.
- In the case of pore pressure sensors the method of installation and the range can play an important role. The designed method (technique) of monitoring should give results in a relevant resolution. Pressure sensors which are designed to be driven in or pushed into soft soil are preferable in the described case.
- In this example monitoring should be undertaken:
- before execution of the embankment, to establish reference conditions (zero-reading);
 - during execution, to identify the appropriate speed of embankment construction (reading after building each 1.6m – 4 layers)
 - after execution, to evaluate the long-term performance of the structure (caused by the traffic or creep of clay in this case, one year periods are suggested initially).
- It is recommended that if the verification of a limit state is sensitive to a specific ground property, the Monitoring Plan should include provisions to verify the design assumptions made for these ground properties. In this case global stability is sensitive to the strength parameter of the weak soil and embankment material. Properties of both should be tested (checked) during the inspection and supervision – see table 4.

3.2.7 Maintenance plan – comments

The maintenance of embankment structures is very limited in practice, or often does not exist. In most cases there are no reference documents for this topic and so it should be agreed between the

parties. In the described case where the monitoring is already installed it can be used during the maintenance period. The frequency of reading should be adapted to the observed results, with a one year period being a potential starting point. The second maintenance aspect could be slope stability and the verification of visible signs of instabilities. While carrying out regular maintenance of the slopes (grass cutting several times per year) the signs of stability failure should be identified. In this case appropriate measures should be taken to prevent failure if possible.

3.3 Case study 2 – Spread foundations

3.3.1 Introduction

This subchapter provides suggested guidelines for inspection, supervision, monitoring, and maintenance plans for pad foundations. In the absence an execution standard for spread foundations, it has been assumed that the plans were developed based on agreement between the parties and taking into account the requirements of EN 1997-1, EN 1997-3 and EN 13670:2009 execution of concrete structures.

The main items that would need to be verified are shown in figures 9, 10 and 11. They are related to both the foundation structure and to the geotechnical component as well. The figures are added to illustrate the content of table 6. What is important is that the information crucial for the design is to be verified – in this example that might be levels, material densities, soil model.

The figures show the most important aspects, but a more extensive checklist could be developed following the examples for other structures shown in the Annex.

3.3.2 Data

This example deals with the pad foundation for a column in a school construction project with the following characteristics:

- Load on the column: 550kN (characteristic combination of the serviceability limit state)
- Cross section of the column: 0.3m * 0.4m
- Grid spacing of column: 5.0m * 5.0m
- No other structures exist in the vicinity of the project

Ground conditions are:

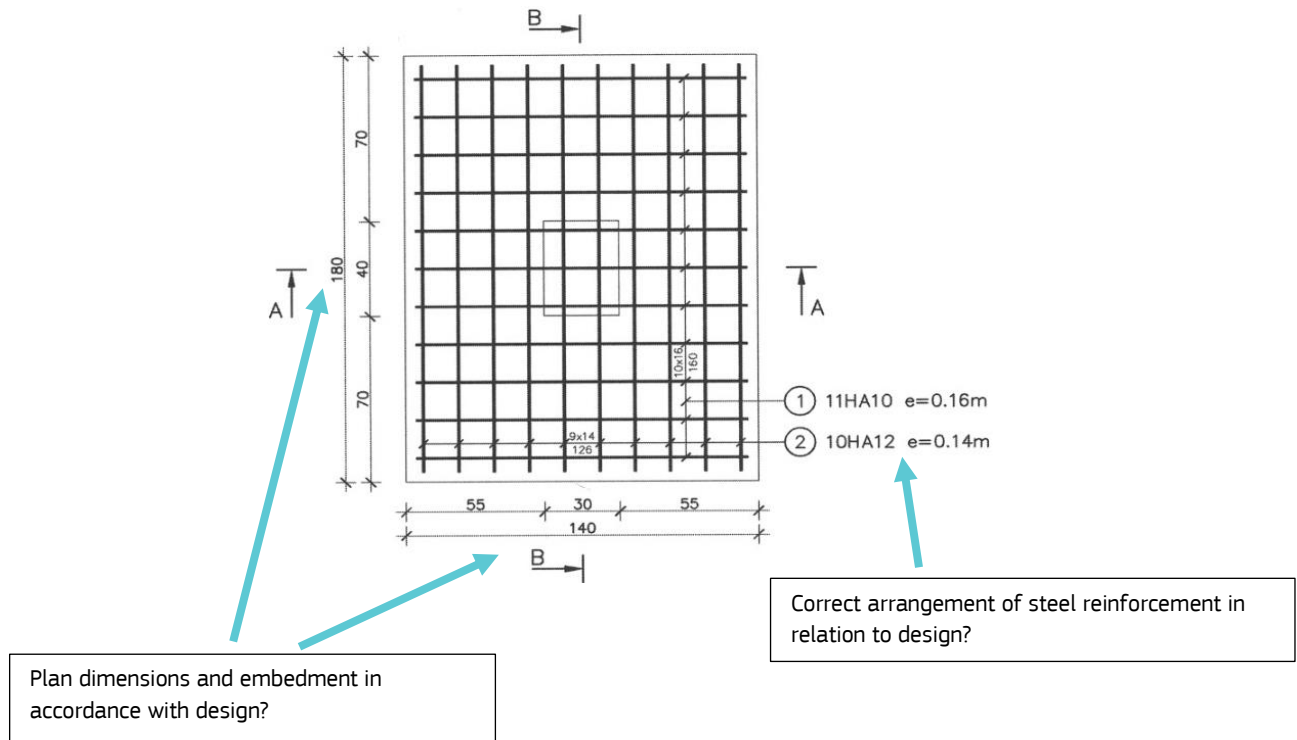
- From ground surface to -8.10m: interbedded sandy / clayey silt and clayey / silty sand with average $N_{SPT}=13$ and $q_c=3.5$ MPa
- From -8.10 to -13.60m: medium dense silty / clayey sand with average $N_{SPT}=18$ and $q_c=4.5$ MPa
- From -13.60 to -20.00m: medium to dense silty sand with trace of gravel and average $N_{SPT}=30$ and $q_c=19.0$ MPa

The ground water level was measured 3.00 m below ground surface. Geotechnical category is GC2.

In order to control settlements, the allowable bearing pressure in the serviceability limit state is limited to 220 kPa.

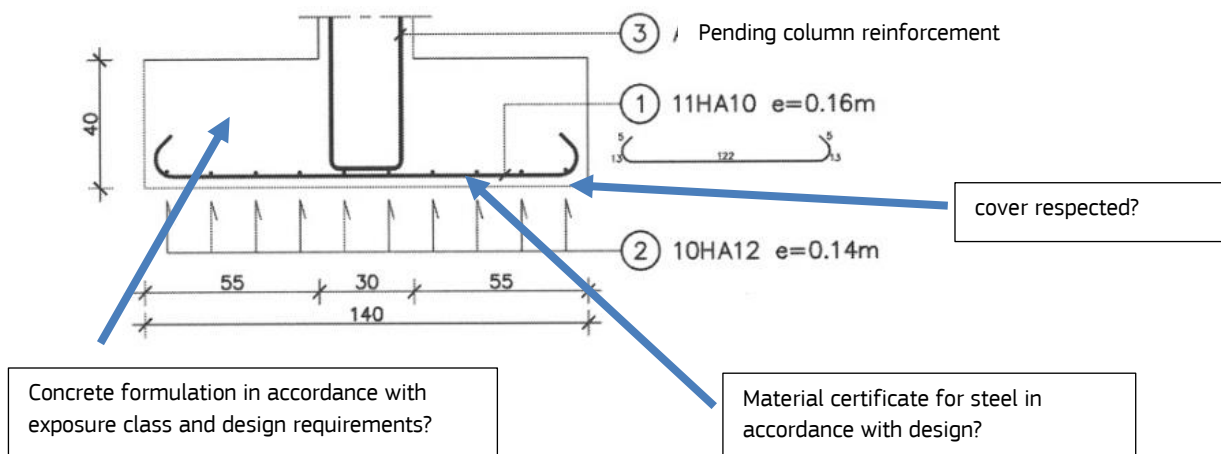
Each column of the building will be founded on pad foundations installed 0.70 m from the ground surface (frost protection requirement is respected).

Figure 8. Plan view of pad foundation



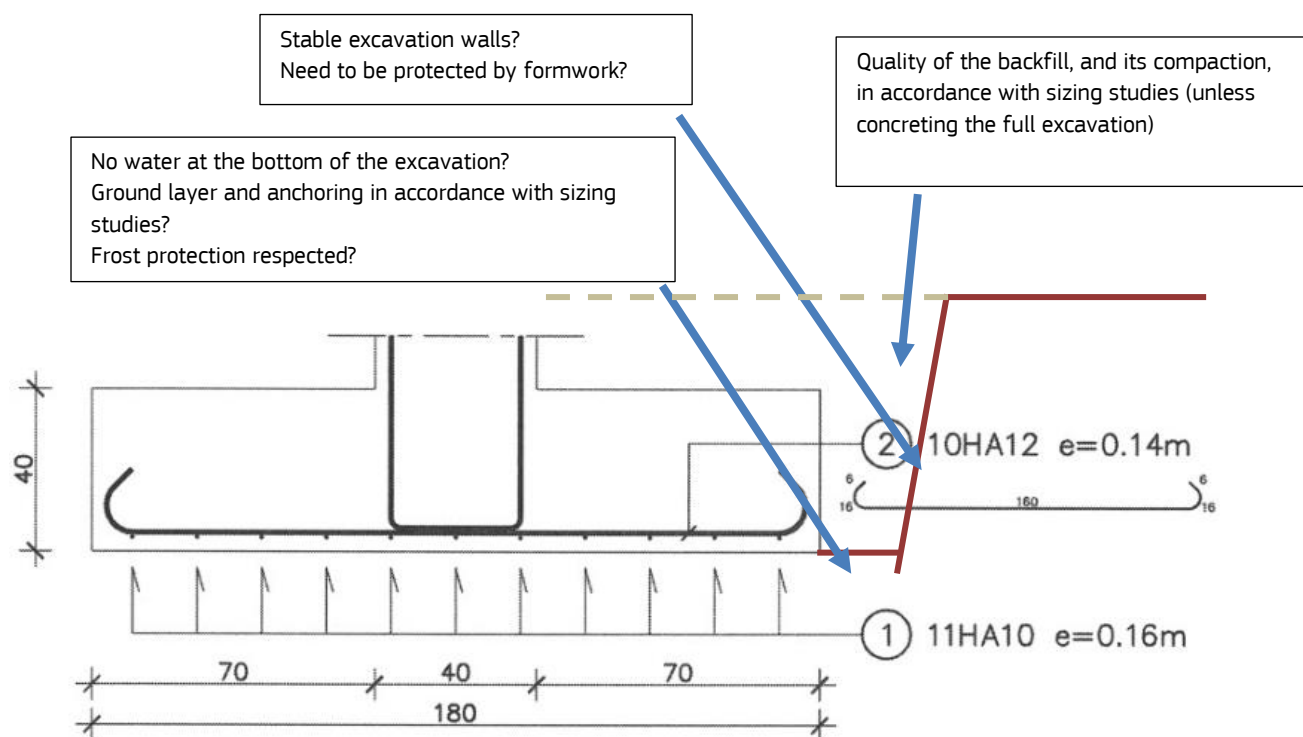
Source: Developed by the Authors

Figure 9. Cross section A-A. Sectional view of pad foundation



Source: Developed by the Authors

Figure 8. Cross section B-B. Sectional view of pad foundation



Source: Developed by the Authors

3.3.3 Summary of the plans for supervision, inspection, monitoring and maintenance

The outcome of this example is table 6, which contains the main information necessary to perform supervision and inspection for the project. The table has the essential outcomes of the design, which should be included in documents supplied for the execution stage, in a prominent position such as in the drawings.

Table 6. Content of plans for supervision and inspection

Parameter	Determination	Relevant code
Geotechnical category	GC2	EN997-1, cl 4.1
Plan dimensions	1.4m * 1.8m	EN1997-3, cl 5.5
Implementation tolerances	25mm (in each direction)	EN13670, Annex G.10.3.
Arrangement of steel reinforcement	11HA10 (e=160mm) & 10HA12 (e=140mm)	EN1992
Concrete cover	30mm	EN1992
Material certificate for steel	B500B	EN1992
Concrete grade	C25/30, XC2	EN1992 / EN206-1
Ground layer at the bottom of the excavation	Interbedded layers of sandy, clayey silt and clayey, silty sand	EN1997-3, cl5.5

Parameter	Determination	Relevant code
Water level	No water at the bottom of the excavation	EN13670, cl8.2(5)
Stability of excavation sides	Stable or protected by formwork	EN13670 cl8.2(6)
Quality of the backfill around spread foundation	Full excavation will be concreted, no backfill	EN1997-3, cl5.5
Compaction of the backfill around spread foundation		

Source: Developed by the Authors

3.3.4 Supervision plan - comments

For this project, the supervision plan may address the following:

- To check if the side of the excavation are stable or protected by formwork:
 - Excavation sides should be stable in the example
- To check if the quality of the backfill, and its compaction, around the spread foundations are in accordance with the design (unless full excavation concreted):
 - Full excavation will be concreted in the example

3.3.5 Inspection plan - comments

For this project, the inspection plan may address the following:

- To check if at the base of the excavation, the bearing material is in accordance with the design assumptions:
 - Interbedded layers of sandy / clayey silt and clayey / silty sand
 - no water
- To check if the plan dimensions and installation tolerances of the spread foundations are in accordance with the design input:
 - 1.4m * 1.8m with a plan tolerance of 50mm (in each direction) in the example
- To check if the arrangement of steel reinforcement matches with the design input:
 - 11 HA10 (e = 160mm) and 10 HA12 (e = 140mm) in the example
- To check if cover depths are respected:
 - 30mm in the example
- To check if the material certificate for the steel is in accordance with the design requirements:
 - B500B in the example
- To check the concrete design is in accordance with the exposure class and design requirements:
 - C25/30, XC2 in the example

3.3.6 Monitoring plan – comments

For this project, the monitoring plan is not required.

Note: Monitoring plan would be required for more complex GC3 projects such as bridges foundations, large vibrating machines foundations, etc.

3.3.7 Maintenance plan – comments

For this project, the maintenance plan is not required.

Note: Maintenance plan would be required for more complex GC3 projects such as bridges foundations, large vibrating machines foundations, etc.

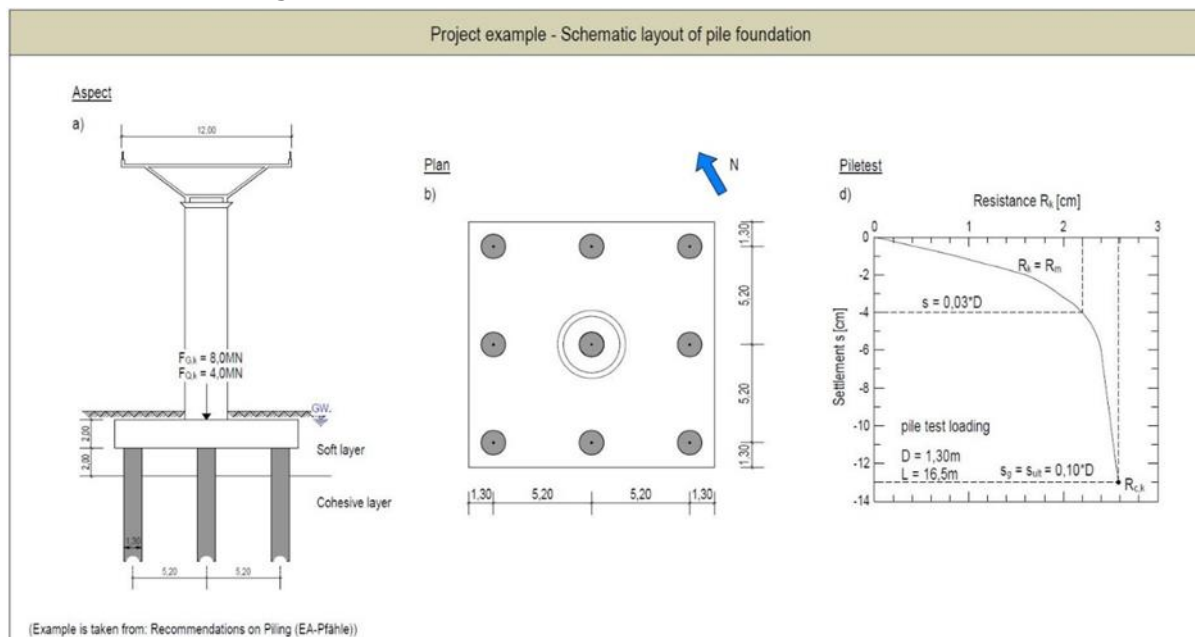
3.4 Case study 3 – Bored piles

3.4.1 Introduction

In the presented example, (see figure 12), a plan for supervision, inspection, monitoring and maintenance is developed. The plan provides the basic determinations, which are necessary for quality control to a level required by EN 1997:2024. The result is summarised in table 7, which contains the main information necessary to implement design into execution for the project. Further guidance is given where additional information in standards related to the subject is found. Where a European standard was not found the relevant national code is quoted. The table as essential outcome of the design, which leads to multiple actions shall be positioned prominently in documents used for tender and execution e.g. in drawings.

An intensive study of the relevant execution standards dealing with bored piles and reinforced concrete and steelworks needs to be carried out alongside the requirements of the plans produced by the design team.

Figure 9. Example bored pile foundation under a highway bridge



Source: German Geotechnical Society, EA-Pfähle

Table 7. Plan for supervision, inspection, monitoring and maintenance

Basic Determinations					
Basic Requirement	Determination			Relevant code and clause	
Consequence class	CC3a–Higher (lower risk group)			EN1990:2021, table 4.1	
Design service life	T _{life} = 100 years			EN1990:2021, table 4.5	
Minimum design quality level	DQL3			EN1990, table B.1	
Minimum design check level	DCL3			EN1990, table B.2	
Geotechnical Category	GC3			EN1997-1, table 4.2 (NDP)	
Minimum Inspection level	IL3			EN1990, table B.3	
Durability design criteria	S _{ULS} = 130mm			EN1990, cl 4.6	
ULS (Settlement with failure of structure or ground)	S _{SLS} = 40mm			EN1990, cl5.3	
SLS (settlement that causes damage to elements other than structural)	Soil & groundwater is not aggressive			EN1990, cl5.4	
Environmental criteria				National documents ⁽¹⁾	
Information relevant to Supervision and Inspection					
Production method	Determination			Relevant Code and clause	
Pile Type	Bored Piles			EN1536 cl 9 & 10	
Drilling method	Kelly piles with casing			EN1536 Annex C.1 & Annex C.2	
Support fluid	none			EN1536 Annex C.3 & Annex C.4	
Geometrical tolerances	Determination			Relevant Code and clause	
Position in plan	e < 0.1*D; 1.0m < D< 1.5m			EN1536 cl 8.1	
Verticality	i < i _{max} = 0.02m/m, f > 86°				
Material	Determination			Relevant Code and clause	
Concrete	C25/30			EN206, EN13670	
Reinforcing steel	500 B			EN1992	
Construction steel	S235			EN1090-2	
Monitoring and Maintenance Plan					
Pile testing	Determination				Relevant Code and clause
Static load test	Test proof load = 2.6MN				EN1536 cl 6.9
Integrity test	Method: low strain integrity test				EN1536 cl 9.2.3.3
Measured variable	Necessary activity/element				
	During construction	After construction			Relevant Code
Settlement of pile head during lifetime	Installation of benchmark on bridge pier Reference measurement after construction	Regular measurement	Period	Documentation	
			3 years	Structure log	

(1) National documents may apply

Source: Developed by the Authors

3.4.2 Basic determinations – quality management measures

3.4.2.1 Determinations and relevant clauses in the code

According to EN 1990-1:2023 clause 4.8 (1) appropriate quality measures should be implemented to provide a structure that corresponds to the design requirements and assumptions. Namely

organizational procedures in design, execution, use and maintenance and further controls at the stages of design, detailing, execution, use and maintenance should be implemented.

This example, a highway-bridge with pile foundations, is in consequence class and geotechnical category three. This structure then to be classified with the accordant design quality, design check and inspection level. The relevant sections of the code are given in table 3.

The maximum allowable settlements in the SLS and ULS are defined depending on the relevant design criteria.

3.4.2.2 Comment

The measures to ensure the required concrete quality are part of EN 206 and EN 13670. EN ISO 17660 regulates welding of reinforcement and EN 1090-2 welding of construction steel and the accordant quality measures. These regulations are not considered within the present example.

3.4.3 Supervision and inspection plan – comments

Depending on the type of pile and the execution method the execution standard defines the measures necessary for quality control during execution. In the case considered, rotary bored Kelly piles with casing are executed, which are treated in EN 1536. Table 8 gives a shortened overview specified in this document for the quality measures required during execution.

Table 8. Quality measures for bored piles during execution, based on EN1536, Table 8.

Number	Subject	Cased/uncased excavation	Excavation supported by fluids	Continuous flight auger piles
1	Identification and as built position 1.1 bored pile reference number 1.2 depth of bored pile Etc.	X X X	X X X	X X X
2	Excavation information 2.1 excavation time Etc.	X X	X X	X X
3	Ground conditions 3.1 Drilling log 3.2 Ground water table Etc.	X X	X X	(X) (X)
4 5 6 7 8 9 10	Support fluid Concreting information Reinforcement Precast concrete elements External grouting Prepacked piles Shaft and base grouting	Sub items for numbers 4 to 10 not listed here		
X: necessary information (X): information as applicable -----: not applicable				

Source: EN 1536

3.4.4 Monitoring and maintenance plans – comments

In this example, static load tests shall be performed in accordance with EN1997-3, clause 6.9.4. The execution of the tests shall comply with EN ISO 22477-1. The test proof load is determined to be 2.6MN. The procedure to develop design pile loads from the pile test is not covered within this example.

To demonstrate that the required quality has been achieved, integrity testing of the piles in accordance with EN 1536, clause 9.2.3.3 should be performed. In addition, the settlement of the pile head is monitored during the service life and measuring bolts are installed in the pile cap. A reference measurement is carried out after construction of the pile foundation and a subsequent measurement after completion of the structure. These actions provide an indication of whether the foundation-settlements are within the limits. The measurements are repeated regularly during the lifetime of the structure. The intervals and measures for documentation are dealt with in relevant national codes.

3.5 Case study 4 – Anchors

3.5.1 Introduction

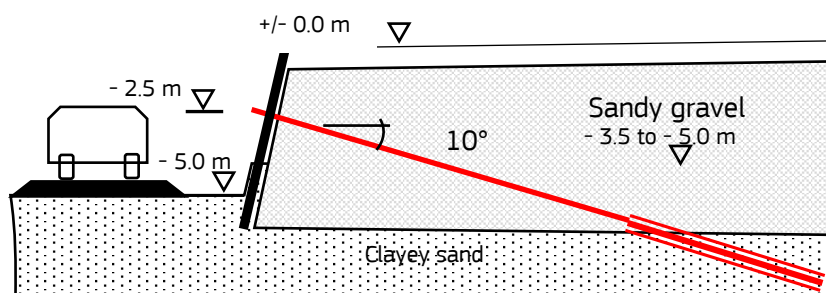
Anchors are specific geotechnical elements where the execution and testing are integrally linked to the design. There are two main documents which the design and the plans should refer to:

- ISO 22477-5:2018 Geotechnical investigation and testing — Testing of geotechnical structures. Part 5: Testing of grouted anchors
- EN 1537:2013 Execution of special geotechnical works - Ground anchors

3.5.2 Data

A cross section of a retaining wall in reinforced concrete to support a 120 m long cut for a new main road is shown on figure 13 and described in the following text.

Figure 10. Geometry and data of the example



Source: Developed by the Authors

- Ground water table: > - 10 m
- Design force per anchor: 400 kN, number of anchors: 60
- Anchor type: grouted anchor, permanent

- Fixed length: 5 m, free length: 7 to 15 m, Inclination: 10°
- Characteristic internal anchor resistance: 558 kN, proof load (investigation tests): min. 558 kN, proof load (suitability and acceptance tests): 419 kN, lock-off load: 335 kN
- Zone of influence: approx. 20 m wide and approx. 10 m deep
- Geotechnical complexity class: GCC2 (normal), Consequence class: CC2 (normal) -> Geotechnical category: GC2. Design service life / durability: 50 years

3.5.3 Plans

A simple example of the content for the plans required is presented in Table 9.

Table 9. Example content for the four plans.

Supervision plan		
Check of anchor products delivery & handling	Specification checks, transport, handling and installation of tendons	
Supervision of the process of borehole drilling	Tolerance of borehole diameter & collar axis at the anchor head. Tolerance of the angle of inclination and borehole axis	EN1537
Grout specification and components	Compatibility with ground conditions	
Borehole testing (to ensure that the fixed length is fully grouted after the grout has set)	Through using water testing, falling grout test or by pressure grouting	EN1537
Supervision of the process of anchor installation	Water/Cement ratio, mixing efficiency and mixing time, grout volume injected/loss of grout volume, injection pressure	
Inspection Plan (all tests must be executed to EN ISO 22477-5 Limiting criteria for investigation, suitability and acceptance tests (EN1997-3, table 8.3))		
Anchor investigation tests (to establish the ultimate load resistance of the anchors at the grout/ground interface)	3 test anchors Test method 1 (the anchor is loaded in steps for one or more load cycles increasing from the datum load to the proof load. At each load step the displacement of the tendon end has to be measured over a fixed time period) Proof load: minimum of 558kN	Limiting criteria: creep rate per log cycle of time: $a_{ULS} = 2\text{mm}$
Anchor suitability tests (to document the ability of the anchor to resist the proof load and assess the behaviour of the anchor system up to proof load in terms of creep rate or load loss)	6 anchors (10% of total number) Test method 1 (see above) Proof load: 419kN	Limiting criteria: creep rate per log cycle of time: $a_{ULS} = 2\text{mm}$
Anchor acceptance tests (to document the ability of the anchor to resist the proof load, the apparent free length and the lock off load)	54 anchors Test method 3 (the anchor is loaded in incremental steps from a datum load to a maximum load. The displacement of the	Limiting criteria: creep rate per log cycle of time: $a_{ULS} = 1.5\text{mm}$

Supervision plan		
	tendon end is measured under maintained load at each loading step) Proof load: 419kN	
Grout material tests	Test of compressive strength, prior to use 2 series of tests for every 20m ³ of mixed grout 3 samples	EN1997-3, cl 8.9.1
Electrical testing of corrosion protection	Every anchor to be tested Anchors to be tested after stressing Test methods: ERM I and ERM II according to EN1537:1999 If feasible test method ERM I should be adopted	Acceptable level: ERM I: > 0.1MΩ ERM II: > 100Ω
Monitoring Plan		
Measurement of forces	3 anchors (5% of all anchors) equipped with monitoring facility Time of measurements: end of construction	
Maintenance Plan		
Measurement of forces	3 anchors (5% of all anchors) 2 additional anchors for validation purposes (tensioning with stressing equipment) Interval: every 10 years	
Electrical testing of corrosion protection	6 anchors (10% of total number) Test method according to EN1537 Interval: every 10 years	
Restressing of anchors	Restressing of individual anchors in the case of declining anchor forces	
Replacement of anchors	In the case of abnormal changes in forces of deformations	

Source: Developed by the Authors

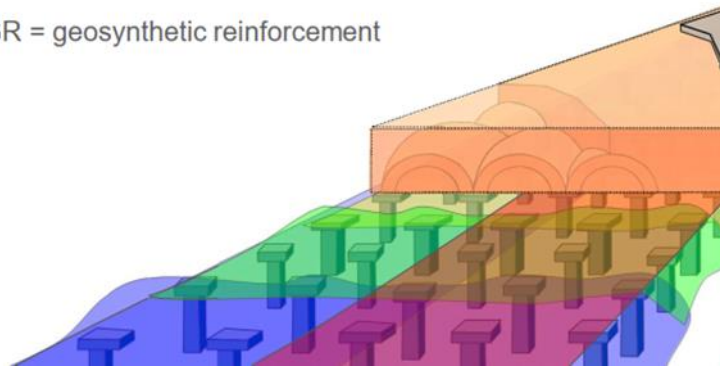
3.6 Case study 5 – Reinforced fill structures

3.6.1 Introduction

A base reinforced piled embankment consists of a reinforced embankment on a pile foundation, see figure 14. Via arching, the force of the super structure is transferred preferentially to the stiffer elements in the ground (in this case, piles).

Figure 11. Base reinforcement under embankment example

GR = geosynthetic reinforcement



Source: Developed by the Authors

Possible references useful for establishing the plans are mentioned below. Please note that these are partially related to the design and partially to execution and contain useful information about the link between those two.

1. CUR226, 2016. Design Guideline Piles Embankments, updated version in Dutch.
2. EN1997-1 : Geotechnical Design- Part 1: General rules including the National Annex.
3. EN1991-2: Actions on structures-Part 2: Traffic loads on bridges, including the National Annex.
4. EN 13242+A1 Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction.
5. EN 14199, 2015. Execution of special geotechnical works – Micropiles
6. EN 14475, 2006. Execution of special geotechnical works- Reinforced fills
7. EN 12699, 2015. Execution of special geotechnical works - Displacement piles
8. EN 13251, 2014. Geotextiles and geotextile-related products-characteristics required for the use in earthworks, foundation and retaining structures

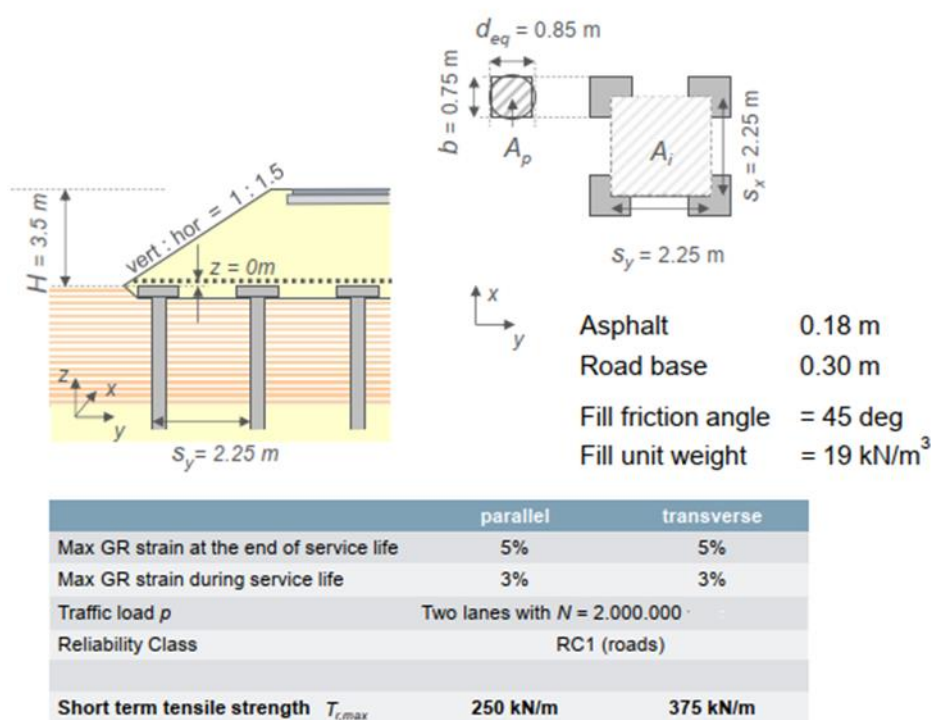
Note: Rules described in the design guidelines for base reinforced piled embankments are dependent on which national standard is used. These standards include design rules on validating conditions, which must be met. However independent of the design method, the implementation and plan content should remain similar – for example it does not matter how the geosynthetic strength was calculated, what is important is how to check / prove it during the execution (inspection in this case).

More important aspects are highlighted but a more extensive checklist of relevant aspects is presented in point 3.9.3.

3.6.2 Data

All the essential data are shown below on Figure 15.

Figure 12. Base reinforcement under embankment example



Source: Developed by the Authors

3.6.3 Supervision plan – comments

- Where reinforcement is to be placed over piles, there should be a chamfer to the edge of the pile caps and/or the pile caps covered with a layer of fill to prevent damage to the reinforcement, (EN 14475 par. 8.3.1.5).
- If required in the design, material to protect the GR from damage by the pile caps should be applied. The foundation shall be constructed to the levels and falls in accordance with the requirements of the design.
- For the aspects of placement of the reinforcement, see EN 14475 par. 8.5.3. Some key points are highlighted below:
 - Reinforcement should be laid on an even surface.
 - Ensure that the non-rigid reinforcement is tight and that any slack has been removed.
 - Reinforcement should extend in one continuous piece in the main load carrying direction.
 - Polymeric reinforcement may be prone to degradation when exposed to sunlight and therefore should be covered with fill within a specified time of laying. Where no such time is specified, exposed reinforcement should be covered within 24 hours of placement.
- For the aspects of placement of the compaction fill, see EN 14475 par. 8.5.4.
- Check if groundwater is according to design. A higher groundwater level in combination with clay or peat at the sides creates risks of instability.

- Check end bearing capacity from blow count analysis for cast-in-situ piles, by means of applied loading force. In case of insufficient load-bearing capacity, it may be necessary to install an extra pile, subject to design review.
- After placing the pile caps, the soil between these pile caps should not be compacted in order to allow some strain of the grid during the execution phase, so the end deformation is reduced.
- During the execution phase, the embankment will not be at its full height. However, working traffic is already acting on the structure. A lower embankment means less arching, thus higher loading of the grid. So, in the execution phase the in-service height of the embankment should comply with the limits set in the design.
- Regarding the granular fill, the following activities during execution should be carried out:
 - Check if the applied reinforcement is in its place. To ensure the position it is recommended to apply a small amount of the fill material.
 - Check that fill material is tipped directly on the GR out of the truck. The truck should tip its load on the already constructed works, after which the material should be spread out evenly over the GR.
 - Check that compaction of layer is according to the compaction requirements (usually at least 98% standard Proctor density).
 - Check that construction equipment is not directly driven on the GR. Add at least a base layer of 0.4 m fill.
 - If the design requires, the reinforcement along the edges should be wrapped back.
- If the edges being wrapped back for some reason is not possible, it should be demonstrated that the force at the toe of the slope from the reinforcement layer to the piles and from the fill to the piles is sufficient.
- If in the design for the grid, a sub grade k_s is taken into account at the end of the service life, this should be guaranteed. The soil properties of the sub soil between the pile should be such that settlement requirements are met.
- Make sure that during execution, the soil between the piles is not overloaded, e.g. by choosing a thicker working platform to avoid settlements (and absence of subgrade).
- Regarding the overlaps, the following activities during execution should be carried out:
 - Avoid unnecessary overlaps in the longitudinal direction.
 - Overlaps in the transverse direction (perpendicular to the strong direction) should lie above the pile caps and not in the span between them.
 - Pile caps should be visible during laying grids, in order to control the correct position of the overlaps. If pile caps are covered, their locations should be marked.
 - Verify if the required overlap in the transverse direction is used in the execution phase.
 - If overlaps are replaced by stitched seams, reduction of reinforcement strength and the change in its strain behaviour should be included in the calculation.
- GR should be installed without folds, creases or undulations, but not pretensioned.

- Without any calculations, the overhang of the pile cap should be at most $0.5d_{eq}$.

3.6.4 Supervision plan – comments

- Observation during construction shall conform with EN 1997-1 (clause 2.7). In EN14475 par. 7.4 and 7.5 some possible aspects of design output are specified.
- Geosynthetic material shall be identified with clear marks or labels and conform to EN ISO 10320.
- For quality control and handling and storage, see EN14475, par. 8.1 and 8.2.
- In the design reduction factors are used based on information provided by the suppliers of the grid (Isochronous curves given by grid manufacturer). Since time can pass between design and execution, these factors should be double-checked with the provider of the grid at time of delivery.
- While using prefabricated pile caps, the connection of both elements should be such that the pile head is supporting the pile cap over the entire contact area. This to avoid peak stress in the pile cap.
- The quality of each pile must be checked after installation if the integrity cannot be guaranteed.
- To ensure that the geosynthetic reinforcement is not damaged at the pile edges, the edges should be rounded off and or provide a protection between reinforcement and pile caps.
- Quality of fill material should be chosen taking into account the imposed environment and structural requirements. Requirements for the reinforced embankment:
 - Inspection of fill. It should not contain any sharp objects that could damage the geosynthetic reinforcement.
 - Check if internal friction angle of design is met.
 - If recycled aggregate is used, check required particle size grading. Recommendation: 0 / 31.5 or 4 / 31.5 mm to 0 / 63 or 4/63 mm according to EN13242.
- Avoid using crushed demolition waste aggregate with low hydraulic conductivity.
- The pile setting out and spacing should be according to design.

3.6.5 Monitoring and maintenance plan – comments

Due to the low settlements expected after construction, this type of construction requires less maintenance. At most the transition from a piled embankment to a conventional embankment may need some maintenance to compensate for any differential settlements. Check if monitoring is needed at transition zone according to the design. If monitoring is needed, measuring hoses can be placed on the grids during execution, to monitor settlement during the execution phase and or during the structure's life cycle.

Future embankment widening or installation of cables and pipelines is difficult. It is crucial to formulate a maintenance strategy for the entire life cycle of the structure.

Figure 13. Example of monitoring arrangement



Source: Developed by the Authors

Some attention points for maintenance:

- For example, incorporation of utilities in advance e.g. empty ducts, or cable tunnels.
- Lowering the surface level adjacent to the pile embankment could lead to horizontal soil deformation that might exert an unsafe loading on the piled embankment.
- During maintenance of the verges and slopes, account should be taken of the presence of the GR.
- A possibility for inspection of material is to enclose non-functional pieces of the GR that are subjected to the same conditions as the “functional” GR. This sample can be tested to obtain information on the rest of the reinforcement present in the embankment.
- Asset manager should check for damage by rodents, termites, etc.

3.7 Case study 6 – Rigid inclusions

3.7.1 Introduction

This part suggests guidelines for inspection, supervision, monitoring, and maintenance plans of a ground improvement project with rigid inclusions (RI). In the absence an execution standard for RI, it is assumed that the plans were developed based on agreement between the parties and taking into consideration the stipulations of both EN 1997-1 and EN 1997-3.

3.7.2 Data

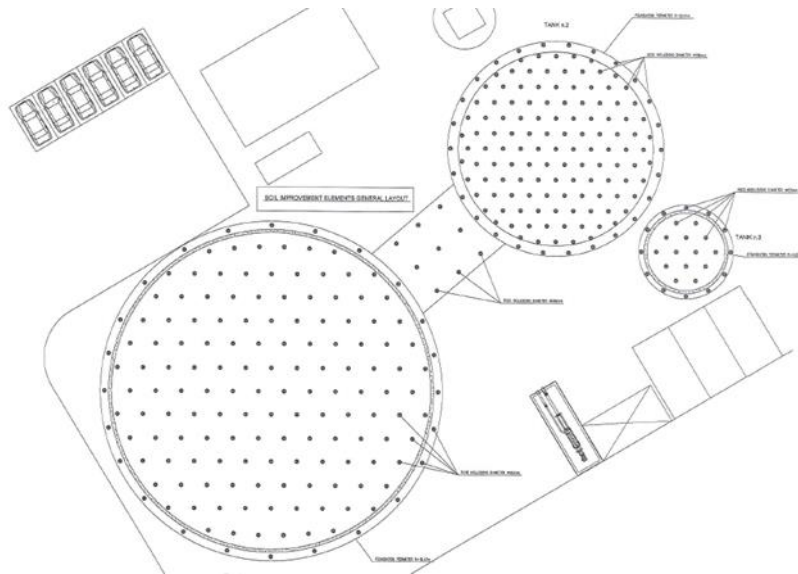
This example relates to a waterfront project with three (3) new tanks for liquid storage shown on figure 17 and 18 with the following characteristics:

Tank 1 (concrete tank) – Foundation diameter 32.94m, average contact pressure 81 kN/m²

Tank 2 (steel tank) - Foundation diameter 21.82m, average contact pressure 171 kN/m²

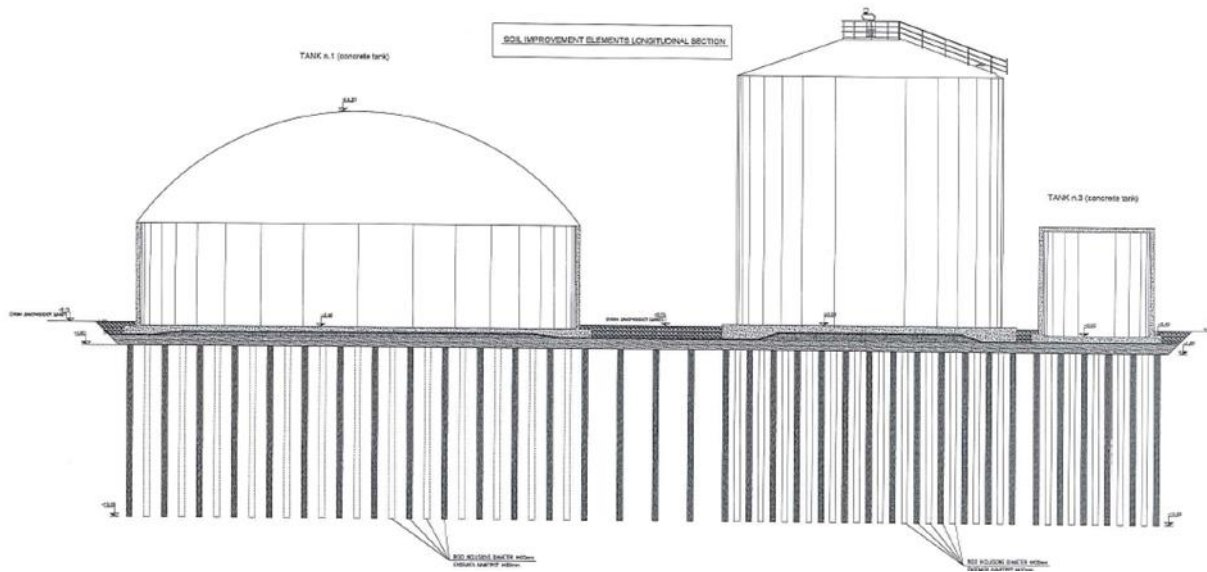
Tank 3 (concrete tank) - Foundation diameter 9.10m, average contact pressure 88 kN/m².

Figure 14. Tanks and rigid inclusion layout



Source: Developed by the Authors

Figure 15. Tanks and rigid inclusion cross section



Source: Developed by the Authors

Soil and groundwater conditions are:

- From ground surface to -2.70 m: soft silty clay with average $N_{SPT}=5$ and $q_c=0.50\text{MPa}$
- From -2.70 to -8.10 m: intercalations of sandy / clayey silt and clayey / silty sand with average $N_{SPT}=13$, $q_c=3.50\text{MPa}$, and $f_s=0.05\text{MPa}$
- From -8.10 to -11.20 m: soft clayey silt with average $N_{SPT}=7$, $q_c=1.0\text{MPa}$ and $f_s=0.15\text{MPa}$
- From -11.20 to -13.60 m: medium dense silty / clayey sand with average $N_{SPT}=18$, $q_c=4.5$ and $f_s=0.2\text{MPa}$

- From -13.60 to -27.00 m: medium to dense silty sand with trace of gravel and average $N_{SPT}=30$, $q_c=19.0\text{MPa}$ and $f_s=0.2\text{MPa}$
- Below this depth the soil is considered as not compressible.

The ground water level was measured 1.50 m below ground surface. No other structures exist in the vicinity of the proposed silos. The ground improvement solution comprises a total of 320 concrete rigid inclusions having a diameter of 400 mm and net length of 13.20 m (starting -1.80 meters below ground surface to -15.00 meters). They are designed as full displacement. In addition, the inclusions are un-reinforced and they are topped by a Load Transfer Platform (LTP) that transfers the structural loads to the RI. The distribution of inclusions is 158 for tank 1, 147 for tank 2, and 15 for tank 3. Geotechnical category is GC2. The design service lifetime is 50 years to match the tank structure.

3.7.3 Supervision plan – comments

Supervision should be performed in accordance with the stipulations of EN 1997-1 section 10.2.

For this project, the Supervision Plan may address the following:

- To execute the works with a special displacement tool and suitable machines, which can apply the necessary torque and pull-down force to the full design depth. To apply the full displacement method in which soil is not extracted but instead it is displaced laterally.
- To ensure that the time between rigid inclusions execution and silos initial filling is appropriate; therefore, the excessive pore pressure can dissipate.
- To execute the inclusions in a specific pattern determined by the execution specifications and which may be adjusted during execution based on observations.
- To assure safety procedures especially in terms of working platforms quality.
- To provide measures during execution in order to ensure the geometrical properties.

3.7.4 Inspection plan – comments

- Inspection has to be performed in accordance with the stipulations of both EN 1997-1 section 10.3 as well as EN 1997-3 section 11.8.2 Inspection and section 11.9 Testing.
- As mentioned earlier in this example, the inclusions are constructed starting from -1.80 meters below ground surface down to -15.00 meters. Thus, the inclusion tip is designed to be inside the final foundation layer (medium to dense silty sand with trace of gravel and average $N_{SPT}=30$ and $q_c=19.0\text{ MPa}$).
- Based on the above, the Inspection Plan may address the following for validating the design assumptions in terms of ground conditions and performing Control Testing:
 - To ensure that a competent bearing layer has been reached it is required to perform calibration drilling (preferably with the aid of bespoke recording equipment) at the beginning of the work in order to define a refusal criterion. The criterion is applied to all inclusions during construction and in case of discrepancies the Designer shall be notified.
 - The volume of concrete necessary for constructing the inclusions shall be recorded with depth (preferably with the aid of bespoke recording equipment) and in case of excessive under or over consumption the Designer shall be notified.

- In terms of bearing capacity, a load test on an individual inclusion shall be performed following the appropriate specifications.
- UCS testing according to table 11.5 of EN1997-3.

3.7.5 Monitoring plan – comments

- Monitoring to be performed in compliance with the stipulations of EN 1997-1 section 10.4.
- The Monitoring Plan should address the following:
 - During construction: Not required.
 - After construction, for the initial filling: Initial filling of the silos shall be performed with a specific loading and monitoring schedule. During this operation, measurements shall be taken at all silos in terms of both absolute and differential settlements. The monitoring results are to be used to verify the design assumptions prior to the start of normal usage of silos.
 - After initial filling, for the service life of the structures: Periodic measurements shall be taken at all silos in terms of both absolute and differential settlements.

3.7.6 Maintenance plan – comments

- Maintenance to be performed in accordance with the stipulations of both EN 1997-1 section 10.5 and EN 1997-3 section 11.8.4.
- The Maintenance Plan should address the following during the course of the service life of the structures:
 - Protect the LTP from erosion and hydraulic phenomena by wrapping it inside geofabrics and if necessary, perform repairs.
 - Rigid inclusions are buried; therefore, no measures are needed.

3.8 Case study 7 – Groundwater control

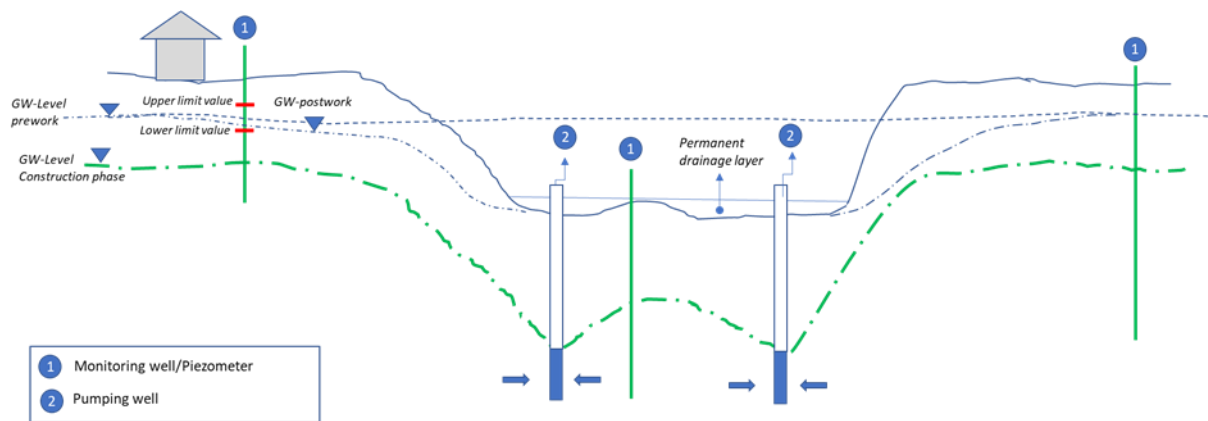
3.8.1 Introduction

A generic case of groundwater control is presented as an example for establishing supervision, inspection, monitoring and maintenance plans. More important aspects are highlighted but a more extensive checklist of relevant aspects is presented in the example checklist in the Annex.

3.8.2 Data – dewatering of an open excavation

- The example shown on Figure 19 represents groundwater control through dewatering by pumping.

Figure 16. Illustration of the example of ground water control through dewatering



Source: Developed by the Authors

- The soil is frictional material representing an unconfined groundwater aquifer
- Groundwater lowering/dewatering will be performed:
 - Temporary during construction phase to mitigate the risk of hydraulic uplift and excessive groundwater ingress while performing open excavation for foundation works.
 - Permanently through drainage of the geotechnical structure.
- The example represents geotechnical category GC3 since there are buildings at risk of groundwater lowering located within the zone of influence. As a consequence, there are limit values for groundwater levels for certain structures within the zone of influence.

3.8.2.1 Key design parameters

- Soil/rock stratification
- Hydraulic units/aquifers
- Hydraulic parameters of soil
- Well capacity of pumping wells
- Extraction volumes
- Robustness of dewatering operation:
 - Stability of excavation (extraction capacity)
 - Mitigation plan in case limit values for groundwater levels are exceeded
- Groundwater levels (Pre-work/Construction phase/Permanent phase):
 - within excavation
 - within the zone of influence
 - at sensitive objects
 - of hydraulic units

- Drainage volumes
- Maintenance measures
- Layout and design of the groundwater control system.

3.8.3 Checking for relevant execution standards

Table 10 can be used to check which standards or documents need to be checked while making the link between the design and execution and writing plans. Plans might include this kind of list at the beginning to show to the execution team what the basis of the plans was and what documents they need to refer to in order to understand the design fully.

Table 10. List of standards potentially relevant to groundwater control (based on example in section 3.8.2)

Geotechnical investigation and testing		Relevant
EN 22282-1:2022	Geohydraulic testing Part 1: General Rules	Y
EN 22282-2:2012	Geohydraulic testing Part 2: Water permeability tests in a borehole using open systems	Y
EN 22282-3:2012	Geohydraulic testing Part 3: Water pressure tests in rock	N
EN 22282-4:2021	Geohydraulic testing Part 4: Pumping tests	Y
EN 22282-5:2012	Geohydraulic testing Part 5: Infiltrometer tests	N
EN 22282-6:2012	Geohydraulic testing Part 6: Water permeability tests in a borehole using closed systems	N
EN 22475-1:2021	Sampling methods and groundwater measurements; Part 1: Technical principles for execution	N
EN 14688-1	Identification and classification of soil; Part 1: Identification and description	Y
EN 14689-1	Identification and classification of rock; Part 1: Identification and description	N
EN 12063	Sheet pile walls	N
EN 12715: 2020	Grouting	N
EN 12716:2018	Jet Grouting	N
EN 14679:2005/AC:2006	Deep mixing	N
EN 1536:2010+A1:2015	Bored piles	N
EN 12699:2015	Displacement piles	N
EN 1537:2013	Ground anchors	N
EN 15237	Execution of vertical drainage	N
EN 1538:2010+A1:2015	Execution of diaphragm walls	N
EN 16228-1:2014	Drilling and foundation equipment - Safety - Part 1 - common requirements	Y

Geotechnical investigation and testing		Relevant
EN 16228-2:2014	Drilling and foundation equipment - Safety - Part 2 - Mobile drill rigs for civil and geotechnical engineering quarry and mining	Y

Source: Developed by the Authors

3.8.4 Supervision plan – comments

The supervision plan may address the following:

- Hydraulic tests and well installation according to execution standards and specification in the design.
- Installation procedures and design of system for groundwater control are appropriate for the pre-conditions stated in the design (ground model) and verified by observations and data from foundation works.
- Safety aspects for personnel. (Traffic arrangements, necessary qualifications for welding (hot) works, drilling rigs, safety protocol for high pressure hoses etc.) A valid measure could be to require work preparations for all works implying risk for personnel or third party.
- Check installation according to design such as installation levels of well screens, filter sand, bentonite sealing, well casing in respect to execution specification.
- Procedure for executing, assessment and documentation of well development process
- Procedure and documentation for testing hydraulic function of well (falling head test)
- Ensure data and observations relevant to design assumptions are communicated to design team to enable corrective measures if needed.

3.8.5 Inspection plan – comments

Some parameters of the inspection plan are also considered in the monitoring plan to check compliance with design assumptions for serviceability criteria.

- The characteristics of the groundwater system relevant to the geotechnical design and effects within the zone of influence shall be considered both before and after execution to ensure that the design is applicable. Relevant parameters: hydraulic conductivity, transmissivity, storage coefficient, groundwater levels/pressure, aquifers, aquitards, hydraulic contact, vertical and horizontal hydraulic gradients. In this case relevant information would be hydraulic properties of soils and soil profile, location and extent of more permeable or impermeable layers, well tests could yield information on hydraulic connectivity and the zone of influence.
- Overall functionality of the dewatering system to achieve sufficient groundwater lowering within and throughout the whole excavation. Test of dewatering capacity from pump and well tests combined with measurements of groundwater levels.
- Assess robustness of groundwater control system and establish contingency measures to mitigate disturbances (power / pumping failures).
- Plan for mitigation measures if the limit values within the zone of influence cannot be maintained, potentially preparations to install infiltration wells.

- Diversion of rainwater and surface water from entering the excavation.

3.8.6 Monitoring plan – comments

- The monitoring plan should include duration, type and frequency of monitoring, and locations of monitoring points.
- Monitor groundwater levels within the excavation to check design requirements of groundwater levels can be maintained over time to prevent hydraulic uplift.
- Frequency and extent of measurements for the different project phases:
 - Groundwater levels
 - Pumping volumes
 - Ground or structure settlements
- Dewatering volumes (total drainage volumes from excavation)
- Volumes of added process water
- The capacity of the groundwater control needs to be assessed for the design lifetime of the groundwater control system. Declining capacities over time due to encrusting of well screens, silting of wells or sumps; wear in pumps, clogging of pumps needs to be handled through installation of additional wells or well rejuvenation.
- Groundwater levels within the zone of influence are kept within requirements (limit or threshold values)

3.8.7 Maintenance plan – comments

The maintenance plan is to address all components necessary for any permanent groundwater control. It would comprise any installations for drainage, infiltration or bypass of groundwater flow. The need for maintenance will be assessed by long term monitoring of parameters reflecting the functionality of the groundwater control system. It could comprise well cleaning, renewed filter development, chemical treatment of wells to prevent clogging of filters.

3.9 Checklists

The use of checklists can be a convenient method to ensure that all items in a plan have been identified and verified as the design requires.

The risk is that these become prescriptive and transferred from one project to the next without a review to revise it as required for the specific project requirements. This could result in an inadequate or overly onerous document being incorporated into the project.

To aid the user of the Eurocode, some template checklists have been included in the Annex. These do not cover all the examples of geotechnical structures covered in this section but could be used as the starting point for those not covered.

There are some types of geotechnical structure, such as grouted anchors, where the execution standard already contains a significant amount of the detail required and so a separate checklist may not be required.

4 Acceptance criteria

4.1 General concept

Setting up acceptance criteria as points of reference for the execution stage is an important part of geotechnical design, linking the design and execution stages.

There are mainly three types of acceptance criteria that should be specified prior to the execution, which can be related to:

- **Allowable execution tolerances** – specifying the allowed deviation of the constructed geometry of the structure such that it is still considered of sufficient quality for use;
- **Performance indicators** – used for comparison of observed behaviour with design predictions, for the purpose of validation of design, i.e. ensuring that the effects of execution are in line with design predictions;
- **Serviceability limit state criteria** – established limiting values of observable quantities characterizing the behaviour of a structure in relation to its serviceability criteria.

Although all these types of criteria should be specified in the design, for execution tolerances, usually reference to a relevant standard offers sufficient guidance for successful implementation of design in execution. However, depending on the structure to be designed, ground conditions and adjacent structures, execution tolerances could be stricter or larger than in the relevant standard.

In contrast, performance indicators and serviceability limit criteria are mostly defined by a designer on a case-by-case basis, with only limited guidance provided in standards, literature, or by comparable experience. As a result, it is almost impossible to specify a universal set of acceptance criteria, which would not require the designer to apply at least some level of engineering judgement.

The acceptance criteria should include not only specified values or ranges of values for the designed structure, but also for all relevant structures within its zone of influence. Acceptable limits related to third party assets are based on the designers' assessment to determine the maximum acceptable impact on an asset in service which is critical for safety, serviceability or maintenance.

It is worth distinguishing the limitations set on performance indicators, which may be related to the underlying uncertainty of design predictions, from those associated with serviceability limitations, which are directly related to limit state design verifications. However, both types are related to limiting values that should be set in design.

In the case of serviceability criteria, further distinction can be made into levels related to: architectural damage (appearance), functional damage (use of structure), and structural damage (safety of structure).

In EN1990 Annex A.1.8 there is informative guidance for serviceability criteria for buildings: vertical and horizontal deformations, vibrations and limiting foundation movements, which may be used when no other criteria are established by the designer, as the guidance is mostly related to aesthetic and serviceability requirements. On the other hand, railway and road authorities often have national criteria for settlements and change in gradient for their structures, which are mostly related to maintaining the functionality of the infrastructure. Therefore, criteria for embankments typically are based on vehicle speed and the required quality of the transport infrastructure.

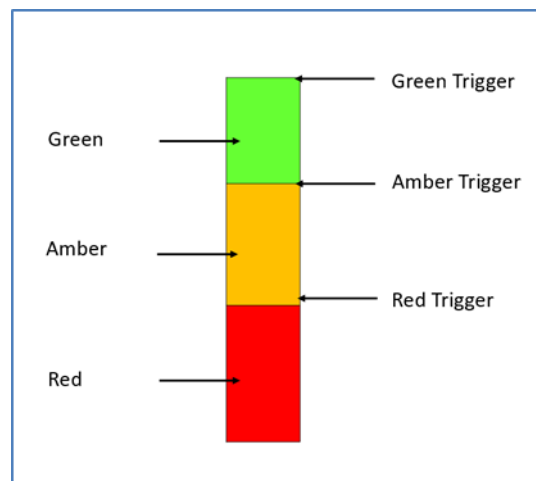
For the implementation of design in execution, the acceptance criteria related to the performance of the structure are often associated with a set of trigger (threshold) values, used as a reference for monitoring. Those trigger values can be related to surface movements, stresses and strain within the support systems, and other parameters critical to the design.

4.2 Setting limits

Limiting values are usually defined in terms of displacements, deformations, strains, groundwater or pore water pressure, vibrations or internal forces that can be measured and assessed during the construction. It is important that any behaviour deviating from the design assumptions, or which may lead to exceeding of a limiting state should be identified as early as possible.

In practice, a color-coding (Traffic signal) system is often implemented to describe the levels of performance (e.g. green / amber / red), which are separated by prescribed monitoring trigger (threshold) values. The aim is to “trigger” a specified action, planned in advance in the case of a given reference value being exceeded.

Figure 19. Illustration of the “traffic light” model for limits



Source: Developed by the Authors

There is no single approach to setting up the threshold values and this process will require engineering judgment. Often, trigger levels are set in reference to predicted values of performance indicators to ensure that the behaviour remains within the design assumptions. However, it is the value of the parameter together with the rate of its change that is important. Breach of trigger levels may indicate incorrect assumptions and result in the revision of values and trigger levels, even a revision of the design.

Green and Amber triggers provide an early warning of a potential problem. The amber level may be set based on the prediction of behaviour using best estimate values of parameters. The amber level in such a case would mean that the predicted level has been reached. Provided that the rate of change of the parameters has stopped, then this would be considered as acceptable. As an example, the Green level may be considered as 75% of the Amber value and the Red value as 150 % of the Amber value (or related to the calculated ULS capacity of the structure being monitored).

Alternatively, trigger values can be related to the serviceability limits, as a percentage lower than 100%, which would represent the assumed limit. This approach can be particularly useful when the predicted deformations are relatively close in value to the limiting values.

Steps to define these limiting values should include:

- **Step 1:** Identifying key performance indicators or observable physical quantities that can be used to assess the performance of a structure in the context of design assumptions and expected serviceability limitations.
- **Step 2:** Assessing limiting values at which the structure is considered to behave too far outside of the design predictions or when the relevant limit states can be exceeded (red level) – when immediate contingency measures need to be undertaken.
- **Step 3:** Assessing limiting values at which sufficient early warning should be provided that there is a risk of falling outside of the design predictions or of exceeding the prescribed limit state (amber level).

Usually, several different monitoring methods (measured indicators/quantities) and locations (structure, ground/groundwater close to construction activity) are needed at same construction site to observe the behaviour of structures and the ground. Some of them are highly correlative (i.e. strains and displacement of anchor head – anchor forces), some moderately correlative (i.e. vertical displacement – horizontal displacements or lowering of GW table – settlements) and some have no or only very slight correlation (i.e. vibration and GW table). When setting the limits, these correlations and the possibility of cross-checking different monitoring results should be taken into account. These correlations can be utilized during execution when analysing the reliability of the measurement results.

An example of selecting a limiting value for the amber level may include considering:

- 50-60% of value at which the serviceability would be exceeded; or
- 110% of value predicted in design – accounting for design prediction with acceptable deviation that is still considered by the designer to be within the acceptable range.

Note: predicted in design (normally) means prognosis, i.e. calculations with best-estimate-values for ground properties and with characteristics loads.

An example of selecting a limiting value for the red level may include considering:

- 90% of value at which the serviceability would be exceeded; or
- 130% of value predicted in design.

In cases where predicted values are close to the serviceability criteria, usually the latter should be used as a reference point for acceptance. However, when serviceability criteria are much higher than obtained design predictions or there is no clear basis for specification of those criteria, it is reasonable to relate the limits to the values of predicted performance of a structure. For example, when considering the lateral deflection of an embedded retaining wall supporting an existing building, limitation can be set based on allowable deformation to the building, whereas, in the absence of any structure within the influence zone, the limitations can be set on the basis of design predictions.

However, if the trigger levels are selected on the basis of predicted behaviour of the structure, in some cases their value may need to be adjusted to the stage of construction, and they should be related to the predicted behaviour at that stage.

It is not possible to prescribe one set of levels that would universally fit all the design situations. The levels of the criteria will often depend on following factors:

- If the impact of the negative performance can be reversed and at what relative effort and cost;
- If there will be sufficient time to implement contingency measures and corrective actions;
- How much margin of safety is needed to implement alternative design solutions.

In general, a different approach should be implemented in situations where contingency measures can be implemented in time and where exceeding the specified criteria means that the structure would no longer be considered useable.

4.3 Guidelines on contingency measures

Below are examples of actions that may be taken when specific trigger levels are exceeded:

Breaching Green Trigger

Review of measurements and trends

Breaching Amber Trigger

1. Cross checking the readings of the instrument with another method (sanity check) and another instrument.
2. Inspection of the assets in the vicinity where the breach has occurred for signs of unpredicted behaviour and/or evidence of distress to the existing assets.
3. Notify all relevant parties.
4. Assess if there is any imminent danger to the stability of the works or third-party assets and establishes the extent of the zone of danger.
5. Evaluation of information and undertaking any analysis required to understand the implications including trends and cause of movements to assess if further movement is likely to be induced.
6. Assess the risk of continuing construction.
7. Initiates re-design and remedial measures including agreeing additional support measures and installations sequences where required.

Breaching Red Trigger

1. Immediately inspects the asset in the area where the breach has occurred for sign of change to the works and existing assets.
2. Place restriction on use of infrastructure including building.
3. Where necessary stop the work and make the site safe.
4. Instigate the action plan and incident management plans.
5. Inform the client.

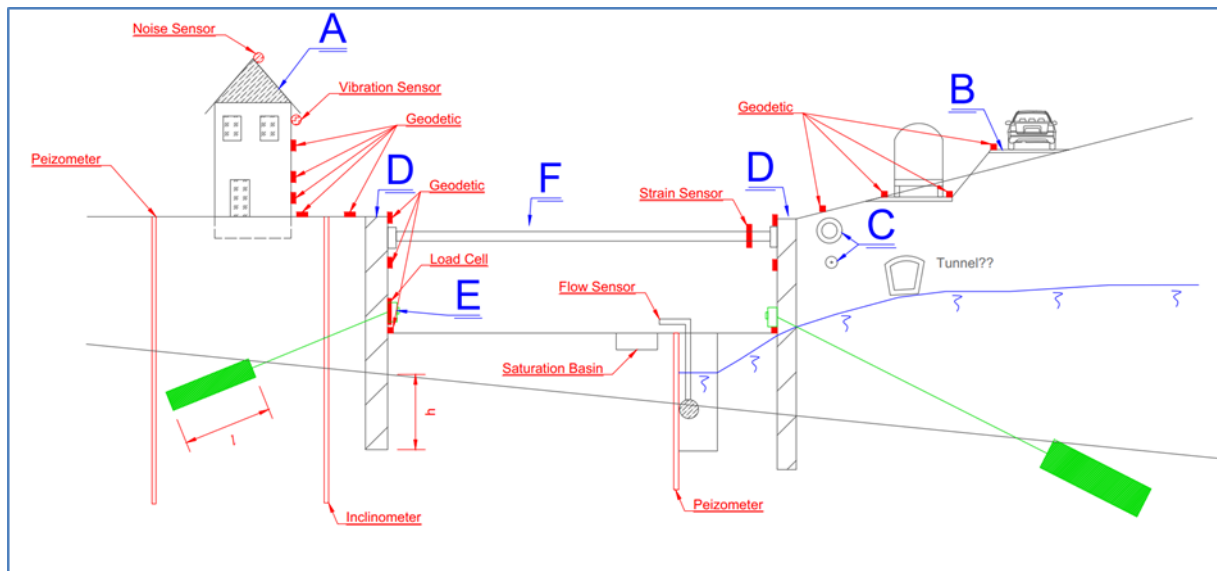
4.4 Case studies

Although each project is different and acceptance criteria should be established on a case-by-case basis, examples are presented below for some typical cases: embedded retaining wall, soil nails and ground anchors, as well as embankments and cuttings.

4.4.1 Embedded retaining wall

Deep excavations supported by embedded retaining walls are among the most complex cases, where acceptance criteria have to be defined. This is mostly due to their common construction in urban areas, where risk to adjacent assets is one of the largest concern, as well as due to the number of structural elements involved. Figure 21 shows a sketch of typical arrangement of an embedded retaining wall in relation to necessary observations to be taken. Examples of acceptance criteria that can be established are summarised in Table 11.

Figure 17. Typical embedded retaining wall sketch



Source: Developed by the Authors

Table 11. Acceptance criteria for Embedded Retaining Wall example

n°	Asset	Parameters	Limit Value		Monitoring				Contingency measures	
			Information needed to establish limit value	Design requirements to meet limit value	Monitoring type	Location	Precision	Frequency of measurement	Measures when amber trigger values are breached	Measures when red trigger values are breached
D	Embedded retaining wall	Displacement (x, y, z)	Geotechnical ground model, loads, use of the area in front of the wall	Semi-empirical methods, numerical methods using finite elements, similar experience (for GC1)	3D targets	In plan: centre of the wall and in elevation: along the depth of the excavation at the surface of the wall.	10% of the Limit Value	1 per week and before & after each excavation stage	Increase monitoring, revisit design, additional propping, review of construction sequence, review of design assumptions	Stop construction. Backfilling Review design parameters and redesign
		Tilt of the wall/ wall deflection	SLS wall deflections, location of struts and props	Limit of deflections to check SLS crack widths	Inclinometers, 3D targets, tiltmeters, tilt sensors	For cantilever wall at the top of the wall and for anchored wall along the depth of the excavation with toe extending to the level where no deflection is predicted.	-	1 per week and before & after each excavation stage	Increase monitoring, revisit design, additional propping, review of construction stages, creation of temporary berms, review of design assumptions	Stop construction, detailed inspection of retaining wall to identify visible signs of distress, review of construction sequence including review of backfilling, introduce emergency support systems
A	Building	Displacement (x,y,z) differential settlement, tilt and tensile strain	Baseline readings, distance from wall, type of foundation, loads, condition surveys, geotechnical ground model	2D or 3D numerical methods to determine settlement distribution	3D laser scan, 3D topographical survey, strain gauges, tiltmeters, tilt sensors	In plan: at the front and the side of the building, two row of vertical target at least for each side Elevation: at least two targets (to check the tilt)	1% of the Limit Value	1 per week and before & after each excavation stage	Frequent monitoring revisit the design Additional struts review of construction sequences, review of design assumptions	Stop construction Backfilling Revisit the design parameters and redesign Stabilize the building
		Vibrations	Sensitivity of the structure (type of structure, design drawings, condition/age of the structure), building	Selection of construction method and work sequence and estimation of vibrations	Vibration sensor and recorder	Closest to the building	-	-	Inspection of building (opening of cracks/other damage), review of design assumptions	Inspection of building (opening of cracks or other damage), if not any damage, evaluation of new

			Limit Value		Monitoring				Contingency measures	
n°	Asset	Parameters	Information needed to establish limit value	Design requirements to meet limit value	Monitoring type	Location	Precision	Frequency of measurement	Measures when amber trigger values are breached	Measures when red trigger values are breached
			inspection (existing cracks etc. in building)	due to construction method and comparing those to allowable vibrations.						limit value. If damage visible, re-design.
	Base of excavation	Heave	Pore-water pressures beneath the base of the excavation, ground water level	Use of 2D or 3D analysis to determine vertical deformation	Extensometers, settlement plates	At the base of the excavation		1 per week and after casting permanent structure	Review of design assumptions. Review of dewatering	Implementation of stabilization technique
B	Ground surface (road/rail or open land)	Surface settlement			Settlement marks, frequent visual inspection	At ground surface close to excavation		Daily during construction	Review of construction sequence, review of other monitoring data e.g. inclinometers, tiltmeters, strain gauges	
E	Anchors	Deformation at head	Project design specifications, geotechnical soil parameters, type, size and capacity of the anchor used		3D Targets	10% of the anchors at anchor heads	1% of the Limit Value	1 per week and before & after each excavation stage	Detail inspection of anchor system, including anchor plates, surrounding support element and anchors to identify visible signs of distress. If possible, redistribute load amongst neighbouring anchors to alleviate stress in breached anchor, introduce temporary support system, adjust construction sequence, reassess design assumptions	Halt construction activities, inspect anchors, retaining wall and surrounding structures, introduce emergency support systems such as additional bracing or shoring to prevent further movement. Install additional anchors
		Load in ground anchor	Anchor loads derived from retaining wall assessment, spacing and inclination of anchors	Tension calculated	Strain gauges attached to anchors, load pins, pressure cells installed	2-3% of the anchors. Load cells at anchor head	1% of the Limit Value	1 per week and before & after each excavation stage	Detail inspection of anchor system, including anchor plates, surrounding support element and anchors to	Halt construction activities, inspect anchors, retaining wall and surrounding

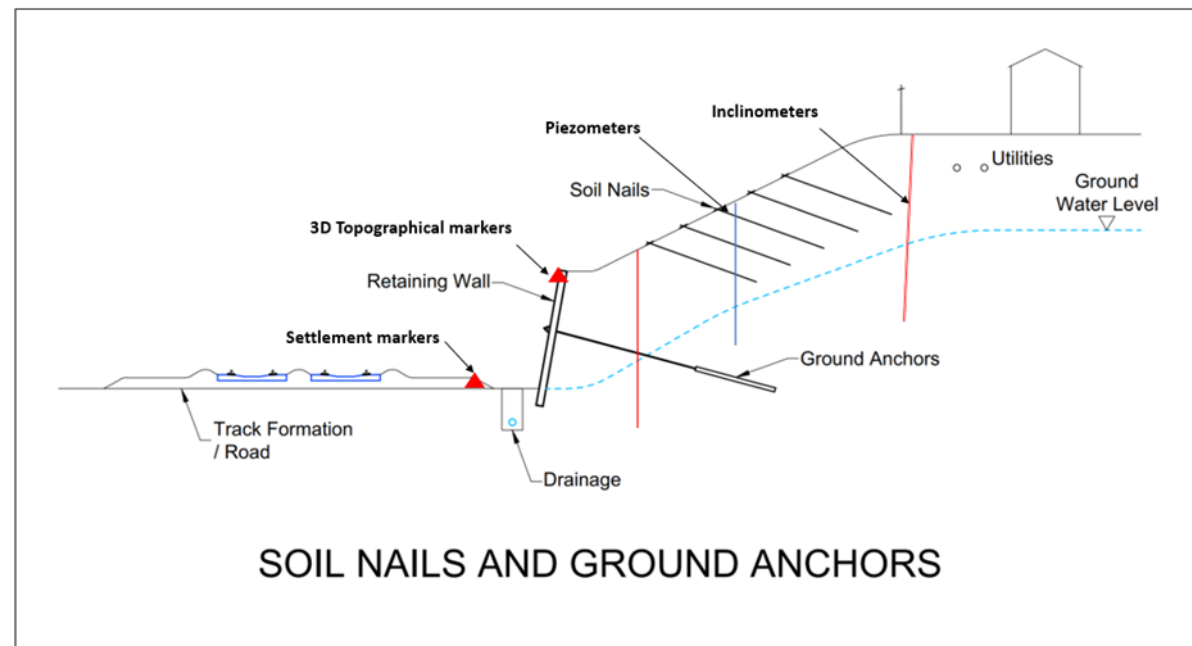
			Limit Value		Monitoring				Contingency measures	
n°	Asset	Parameters	Information needed to establish limit value	Design requirements to meet limit value	Monitoring type	Location	Precision	Frequency of measurement	Measures when amber trigger values are breached	Measures when red trigger values are breached
					in the grout or behind the anchor head to measure pressure exerted by the anchor on the surrounding medium, load cells				identify visible signs of distress. If possible, redistribute load amongst neighbouring anchors to alleviate stress in breached anchor, introduce temporary support system, adjust construction sequence, reassess design assumptions	structures, introduce emergency support systems such as additional bracing or shoring to prevent further movement. Install additional anchors
F	Strut	Strain, temperature, load	Load to carry, length, position, inclination		Strain gauge, Load cells, pressure cells, extensometers					
C	Utilities	Displacement, Strain	distance from the wall, depth, type	finite elements or beam on spring +empirical method (Clough and O'Rourke, Bowles, Hsieh & Ou)	Topographic survey					

Source: Developed by the Authors

4.4.2 Soil nails and ground anchors

An example of typical arrangement of a slope supported by soil nailing and ground anchors is presented in Figure 22. Potential acceptance criteria for such geotechnical structures are presented in Table 12.

Figure 18. Typical soil nail and ground anchors arrangement



Source: Developed by the Authors

Table 12. Acceptance criteria for Soil Nail and Ground Anchor example

n°	Asset	Parameters	Limit Value		Monitoring				Contingency measures	
			Information needed to establish limit value	Design requirements to meet limit value	Monitoring type	Location	Precision	Frequency of measurement	Measures when amber trigger values are breached	Measures when red trigger values are breached
A	Soil nail/anchors	Corrosion	Soil composition, ground water chemistry, presence of corrosive agents	Material selection, protective coatings, cathodic protection, establishing a design life expectancy for the soil nail or anchor, corrosion allowance	Visual inspection of corrosion protection of accessible parts of anchor head, electromagnetic testing, small samples of similar material to be installed in close proximity to the structure					
		Stresses in anchors	Results of geotechnical design and characteristic properties of steel rod (anchors)	Capacity of the anchor	Strain gauge or load cell	Fixed to the anchors		During the work, depending on the type of structure	Inspection of the embankment or cutting for visible signs of failure, review of design assumptions	Stop construction Backfill Revisit the design parameters and redesign
		Movement / deformation	Geotechnical ground model, loads, use of the area in front of the wall)	GC3: Numerical methods implementing non-linear stress-strain relations for the soil; GC2: Semi-empirical methods and numerical methods based on spring model;	Inclinometers, 3D topographical markers	Face plate or concrete structure			Frequent monitoring revisit the design Review of construction sequences	Stop construction Backfilling Revisit the design parameters and redesign

			Limit Value		Monitoring				Contingency measures	
n°	Asset	Parameters	Information needed to establish limit value	Design requirements to meet limit value	Monitoring type	Location	Precision	Frequency of measurement	Measures when amber trigger values are breached	Measures when red trigger values are breached
		Rupture of grout	Pull out test / Sacrificial test	Traditional ULS calculation	Monitoring the displacement of the head	Head of anchor or soil nail or connected structure		Only during pull out testing, if connected to a structure then it should be in accordance with monitoring of the structure		
B	Embankment	Ground Movement / deformation	Composition of embankment material, geological formation of the foundation of embankment, ground water level, seasonal variation, change in use of embankment		Surface crack monitoring using visual surveys, settlement markers (settlement pins or 3D target), piezometers, rainfall and weather stations, use of LiDAR, satellite imagery, acoustic emission monitoring, vibration monitoring	Inclinometers to be placed at crest, toe & mid-slope, key transition zone where soil type or slope angle changes, areas prone to slippage with history of instability		Weekly/monthly		
		Lateral movement			Inclinometers/3D markers					

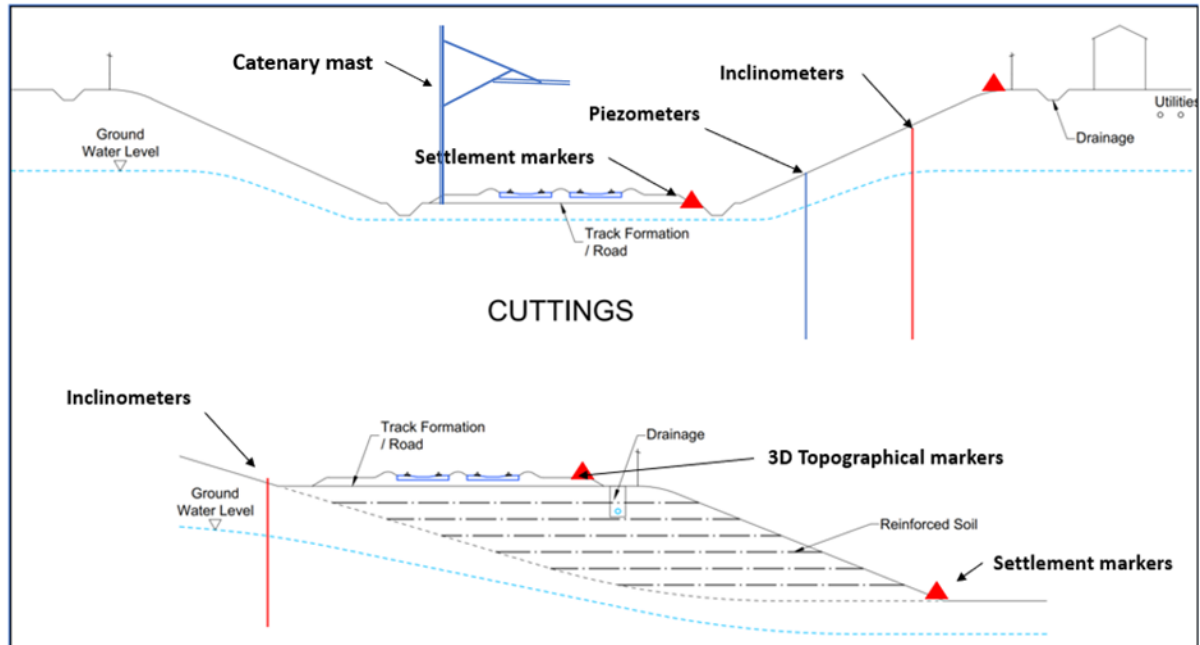
			Limit Value		Monitoring				Contingency measures	
n°	Asset	Parameters	Information needed to establish limit value	Design requirements to meet limit value	Monitoring type	Location	Precision	Frequency of measurement	Measures when amber trigger values are breached	Measures when red trigger values are breached
C	Retaining structure	Tilt	Results of global stability analysis of retaining structure, surcharge loading, ground water level, drainage behind the structure	Design loads, soil pressure, water pressure, effective drainage system to mitigate hydrostatic pressures behind the wall, backfill material, material properties. Establish deformation limits	Tiltmeter / 3D prisms, inclinometers behind the wall	On the face of the retaining structure		Weekly / monthly	Increase monitoring, revisit design, additional propping, review of construction sequence, review of design assumptions	Stop construction, detailed inspection of retaining wall to identify visible signs of distress, review of construction sequence including review of backfilling, introduce emergency support systems
		Horizontal movement (sliding)	Results of global stability analysis, drainage behind the wall, ground water level		Inclinometers/3D markers	At the toe of the structure		Weekly / monthly	Review of design assumptions, introduce temporary support system e.g. installation of anchors, driving a sheetpile in front of the wall	Halt construction and review design assumptions & construction sequence

Source: Developed by the Authors

4.4.3 Embankments and cuttings

Examples of typical arrangement of a cutting and an embankment are presented in Figure 23. Potential acceptance criteria for such geotechnical structures are presented in Table 13.

Figure 19. Typical embankment and cutting example



Source: Developed by the Authors

Table 13. Acceptance criteria for Embankment and Cuttings example

n°	Asset	Parameters	Limit Value		Monitoring				Contingency measures	
			Information needed to establish limit value	Design requirements to meet limit value	Monitoring type	Location	Precision	Frequency of measurement	Measures when amber trigger values are breached	Measures when red trigger values are breached
A	Embankment/ Cuttings	Settlement of embankments due to sub surface features including mine workings.	Historical information, mining risk assessment	Is design criterion ULS or SLS ?	Settlement markers/ inclinometers/ pore water pressure	Toe and crest		Before construction: monthly, during construction: daily, after construction: daily or weekly depending on trigger levels		
		Ground movement / deformation due to; -Shrink & swell -Heave due to unloading in cuttings -dissipation of excess pore water pressure	Composition of embankment material, geological formation of the foundation of embankment, ground water level, moisture content in soil, historical data (records of ground movements or deformation at the site) slope geometry, seasonal variation, change in use of embankment, load acting at crest of cuttings and embankments, baseline monitoring data		Surface crack monitoring using visual surveys, Settlement markers (settlement pins or 3D target), piezometers, rainfall and weather stations, use of LiDAR, satellite imagery, acoustic emission monitoring, vibration monitoring	Inclinometers to be placed at crest, toe and mid-slope, key transition zone where soil type or slope angle changes, areas prone to slippage with history of instability, settlement markers on surface, for heave at base of the cutting		Weekly/monthly, continuous, or real-time monitoring system in critical areas for immediate detection of changes	If slope instability is detected, undertake measures such as grading, terracing or soil reinforcement to prevent further movement, drainage enhancement, monitoring system calibration, review design parameters, develop emergency response plan, establish a routine schedule for periodic inspection	Suspend operation of rail or highway on embankment and in cuttings, activate emergency response plan, detailed visual inspection, implementation of temporary stabilization measures which includes installing retaining structures, reinforcing critical points.

			Limit Value		Monitoring				Contingency measures	
n°	Asset	Parameters	Information needed to establish limit value	Design requirements to meet limit value	Monitoring type	Location	Precision	Frequency of measurement	Measures when amber trigger values are breached	Measures when red trigger values are breached
B	Rail or Highway infrastructure	Displacement (x,y,z) differential settlement, track geometry measurement			Visual inspection, surface settlement marker (3D target), remote sensing	Toe and crest		Weekly / monthly		
		Vibrations			Geo-phones, accelerometers, seismometers	Toe and crest near the track and at specific locations such as track junctions, curves.		Continuous monitoring during operations	Review of construction methods	
C	OLE foundation & catenary, Signal foundations, gantries	Settlement of foundations, tilts of Catenary mast using tiltmeters.	Permissible deflection limits of catenary mast as per standards.		Settlement markers/tiltmeter / targets for topographical survey.	Settlement measurement at the base of the mast, tilt along the height of the mast structure.		Weekly / monthly		

Source: Developed by the Authors

5 Implementation of Design and use of Execution Standards

5.1 General

The execution standards for specialist geotechnical works are a series of companion documents to cover the construction phase of the project. The concept is that such works would have been designed using the current versions of EN1990, EN1997, and other associated design codes.

The execution standards are reviewed on a 5-year rolling basis, though revisions do not always result. As a consequence, it is the responsibility of the project team to ensure that the most recent version is being used or referenced in contract documentation.

5.2 Interaction between design and execution standards

There is overlapping content within the design codes and execution standards with each covering aspects that are more normally considered to be the remit of the other.

It is important to ensure that when reviewing the design content of the execution standards, or items relating to construction within the design codes, an appropriate weighting is given to the topic, in relation to the overall theme of the document.

The design references within the execution standards have mostly been removed, where appropriate. Where some still remain, it is expected that these will be reviewed, and a decision taken on whether to remove or amend the standard, as a part of the process of systematic reviews. EN1997 would normally set precedent on purely design matters though there are issues which have both a design and an execution aspect to them (e.g. concrete cover), and both sets of documents need to be considered.

The execution standards have been written with input from industry to ensure that they are in line with current practice. It is important to ensure that the designer does not specify items that conflict with the execution standards as this could compromise the quality of the final product or create problems with the process of construction.

If conflicts are identified for specific project, they should be discussed between the design and execution teams to ensure the best outcome for the project – ensure that design intent is achieved without specifying methods that compromise execution.

6 Conclusions

The second generation of EN1997 places a clear requirement on the designer to consider the implementation of the design in execution and not to focus only on the analysis and verification of limit states. To this end there are a series of plans required to be produced by the designer to help manage this process, and to achieve the expected level of quality assurance, appropriate to the potential consequences and complexity of ground-structure interaction. For this purpose, EN1997 sets general rules to be followed. However, it is recognised that more specific guidance and examples are useful to foster the implementation of those rules in national practices and to better understand the intent behind the requirements and recommendations presented in the code.

This document aims to give guidance to the designer on how to meet the requirements placed on them in the design codes, whilst respecting the practicalities of the construction of special geotechnical works, as reflected in the execution standards.

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List of abbreviations and definitions

Abbreviations	Definitions
ABS	Acrylonitrile Butadiene Styrene (thermoplastic polymer)
ACE	Association for Consultancy and Engineering
AIA	American Institute of Architects
APM	Association for Project Management
BIM	Building Information Model
CC	Consequence Class
CPT	Cone Penetration Test
GBR	Geotechnical Baseline Report
GC	Geotechnical Category
GCC	Geotechnical Complexity Class
GCR	Geotechnical Construction Record
GDR	Geotechnical Design Report
GIR	Ground Investigation Report
GR	Geosynthetic reinforcement
GW	Groundwater
HOAI	Honorarordnung für Architekten und Ingenieure
OLE	Overhead Line Equipment
LTP	Load Transfer Platform
NATSPEC	National Building Specification
NZCIC	New Zealand Construction Industry Council
RI	Rigid Inclusions
RIBA	Royal Institute of British Architects
SLS	Serviceability Limit State
UCS	Unconfined Compressive Strength
ULS	Ultimate Limit State
ZOI	Zone of Influence

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Annexes

Annex 1. Example checklists for plans

Checklist: Spread foundation				
Project Information				
Project number				
Project				
Subject				
Remarks				
Procedure	Related codes			
1 General requirements	- EN 1990			
2 Supervision	- EN 1991			
3 Inspection	- EN 1992			
4 Monitoring	- EN 1997-1, EN 1997-3			
5 Maintenance	- EN 13670:2013 Execution of concrete structures			
General requirements				
Item	N.A.	Check	Value	Remarks
Consequence class				
Geotechnical complexity class				
Geotechnical category				

Allowable absolute settlement				
Allowable differential settlement				
Other structures within zone of influence?				
Design service life				
General remarks				

Supervision				
-------------	--	--	--	--

Item	N.A.	Check	Value	Remarks
Dimensions as per project design?				
Implementation tolerances in accordance with design?				
Steel reinforcement placing as per with design?				
Any coatings are as per design?				
Material certificates for steel reinforcement meet specification?				
Concrete mix design meets to design exposure class?				

Base of excavation compact & dry before placing reinforcement and concrete?	☐	☐	☐	
General remarks				
Inspection				
Item	N.A.	Check	Value	Remarks
Ground model: are the soils at the base of the excavation as per design assumptions?	☐	☐	☐	
Frost protection respected?	☐	☐	☐	
Excavation sides stable or require temporary works?	☐	☐	☐	
If backfill used, is compaction to specification?	☐	☐	☐	
General remarks				
Monitoring				
Item	N.A.	Check	Value	Remarks
	☐	☐	☐	
	☐	☐	☐	

General remarks	Often not required. May be required for GC3 structures such as bridges or large machine bases.
Maintenance	
General remarks	☐ ☐ ☐ ☐ Often not required. May be required for GC3 structures such as bridges or large machine bases.

Checklist: Embankment	
Project Information	
Project number	
Project	
Subject	
Remarks	
Procedure	Related codes
1 General requirements	- EN 1997-1, EN 1997-3
2 Supervision	- EN 16907-2, EN 16907-3, EN 16907-5

3	Inspection	- EN 16907-2, EN 16907-5, EN ISO 17892 Parts 5,9,10		
4	Monitoring	- EN-ISO 18674 parts 1-5		
5	Maintenance	- local guidelines		
General requirements				
Item	N.A.	Check	Value	Remarks
Consequence class				
Geotechnical complexity class				
Geotechnical category				
Allowable absolute settlement				
Allowable differential settlement				
Other structures within zone of influence?				
Design service life				
General remarks				
Supervision				
Item	N.A.	Check	Value	Remarks
Construction stages in line with project design?				

Execution of earthworks to EN16907-3?	☐	☐	☐	
Filling & compacting to EN16907-3 and EN16907-5?	☐	☐	☐	
Stage duration in line with project design?	☐	☐	☐	
General remarks				

Inspection				
Item	N.A.	Check	Value	Remarks
Are materials to specification, with documented proof?	☐	☐	☐	
Materials for each layer to EN16907-2?	☐	☐	☐	
Materials properties for each layer to EN16907-2?	☐	☐	☐	
Is friction angle of embankment material verified? Is this to project specification?	☐	☐	☐	
Has elastic modulus of embankment material been determined? Is this to project requirements?	☐	☐	☐	
Has relative density of embankment material been determined? Is this to project requirements?	☐	☐	☐	

Was stiffness & bearing capacity of subsoil checked? Is this to EN16907-5 and project requirements?	☐	☐	☐	
Was quality of drainage system checked?	☐	☐	☐	
Have other works been carried out which could provide extra data on the ground model?	☐	☐	☐	
Is subsoil homogenous, or are there areas of variation?	☐	☐	☐	
General remarks				

Monitoring				
Item	N.A.	Check	Value	Remarks
Monitoring installed top project requirements?	☐	☐	☐	
Baseline readings taken & instrumentation working?	☐	☐	☐	
Instrumentation to EN-ISO 18674 series?	☐	☐	☐	
Are expected physical readings defined?	☐	☐	☐	
Are timesteps for readings known?	☐	☐	☐	
	☐	☐	☐	

General remarks	In the simple embankment case, no monitoring is usually needed. When weak subsoils are present, monitoring becomes necessary.
Maintenance	
General remarks	The maintenance of embankments structures is limited in practice. In most cases there are no reference documents for the topic. This will need to be agreed between the parties prior to the project design & implementation.

Checklist: Groundwater Control	
Project Information	
Project number	
Project	
Subject	
Remarks	

Procedure	Related codes
1 General requirements	- EN 1990
2 Supervision	- EN 1991
3 Inspection	- EN 1992
4 Monitoring	- EN 1997-1, EN 1997-3
5 Maintenance	-

General requirements				
Item	N.A.	Check	Value	Remarks
Consequence class				
Geotechnical complexity class				
Geotechnical category				
Other structures within zone of influence?				
Design service life				
General remarks				

Supervision				
Item	N.A.	Check	Value	Remarks

Correct installation of pumping or infiltration wells?	☐	☐	☐	
Correct installation of monitoring wells or piezometers?	☐	☐	☐	
Correct execution of procedure for reduction of hydraulic permeability?	☐	☐	☐	
Execution of geohydraulic testing according to EN22282	☐	☐	☐	
Execution of reduction of hydraulic conductivity according to grouting EN 12715, jetgrouting EN12716	☐	☐	☐	
Execution of barriers according to EN1538- Diaphragm walls, EN12063-sheetpile walls	☐	☐	☐	
Execution of deep mixing according to EN14679	☐	☐	☐	
Execution of vertical drainage according to EN15237	☐	☐	☐	
Execution to project specification?	☐	☐	☐	

General remarks				
Inspection				
Item	N.A.	Check	Value	Remarks
General principles	The characteristics of the groundwater system relevant for the geotechnical design and effects within the zone of influence shall be considered both before and after execution to ensure that the design is applicable. Relevant parameters include: hydraulic conductivity, transmissivity, storage coefficient, groundwater levels, groundwater pressure, aquifers, aquitards, hydraulic contact. Inspection can be performed by observation, measurement or testing			
Groundwater levels comply with design assumptions				
Effect of dewatering on groundwater levels/pressure within zone of influence				
Effectiveness of groundwater control systems for dewatering for purpose of stability of slope or base of excavation or infiltration to reduce impact of dewatering/drainage				
Chemical composition of groundwater in relation to design assumptions for durability				
Robustness of groundwater control systems to maintain required levels				

Verify that reduction in hydraulic conductivity matches design requirements				
Absence of flow ingress/egress and/or monitoring of groundwater levels on both side of the barrier/zone of reduced hydraulic conductivity				
General remarks				

Monitoring				
Item	N.A.	Check	Value	Remarks
General principles	Groundwater levels and/or groundwater pressure shall be monitored prior, during and after groundwater control works and works affecting groundwater levels			
Groundwater levels to be checked for compliance with design requirements				
Groundwater levels, leakage rates & changes in water levels due to groundwater control measures				
Pumping rates within expected volumes				
Is discharge water showing changes in chemical composition or signs of fines				

Ground surface settlement	☐	☐	☐	
Settlement of structures within zone of influence	☐	☐	☐	
Raised groundwater levels outside a barrier due to damming effects	☐	☐	☐	
	☐	☐	☐	
General remarks				

Maintenance				
Item	N.A.	Check	Value	Remarks
General principles	The maintenance plan shall include objectives, types, frequency of activities required to ensure the structure can be used for its intended purpose without major repair during its design service life.			
Check critical items of groundwater control system to ensure design requirements can be maintained	☐	☐	☐	
The objective type and frequency of post-execution inspection	☐	☐	☐	
Acceptance criteria for critical items of the groundwater control system	☐	☐	☐	

Activities if acceptance criteria is not fulfilled				
General remarks				

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