The Concepts of Eurocode 7 for Harmonised Geotechnical Design in Europe

by

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Course Objectives

At the end of this course, each participants should:

• Be aware of the development and operation of the Eurocodes
• Understand the concepts and key features of Eurocode 7
• Appreciate the issues that arose in preparing Eurocode 7
• Be able to design to Eurocode 7:
  – A spread foundation
  – A pile foundation
  – A retaining structure
  – A slope
• Be able to design so as to avoid the occurrence of a ULS or an SLS
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<td>5c</td>
<td>Implementation of Eurocode 7 and future development</td>
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Session 1a

Introduction and Overview of the Eurocodes and Eurocode 7
What are the Eurocodes?

• The Eurocodes are a pan-European set of design codes for building and civil engineering works

• They presently serve as alternatives to the existing national design codes in Europe and will eventually replace them, for example they will replace the national design codes published by the Polish Standards Institution

• They provide a common understanding regarding design between owners, users, designers and contractors in civil and structural engineering throughout Europe

• The Eurocodes are due to supersede the existing national codes in Europe from 31 March 2010
The Suite of Eurocodes

Eurocodes consist of the following 10 codes covering main areas for the design of buildings and civil engineering works:

• EN 1990 – Eurocode: Basis of Structural Design
• EN 1991 – Eurocode 1: Actions on Structures
• EN 1992 – Eurocode 2: Design of Concrete Structures
• EN 1993 – Eurocode 3: Design of Steel Structures
• EN 1994 – Eurocode 4: Design of Composite Steel and Concrete Structures
• EN 1995 – Eurocode 5: Design of Timber Structures
• EN 1996 – Eurocode 6: Design of Masonry Structures
• EN 1997 – Eurocode 7: Geotechnical Design
• EN 1998 – Eurocode 8: Design of Structures for Earthquake resistance
• EN 1999 – Eurocode 9: Design of Aluminium Structures

Sub divided into 58 Parts covering specific aspects of each area
Objectives of the Eurocode Programme

• To improve the internal market
• The European Commission sought to achieve this by eliminating the technical obstacles to trade in Europe due to the existence of different national design standards through the creation of a set of common harmonised design standards based on a common design method for all construction materials
• The Eurocodes serve as a framework for drawing up harmonised technical specifications for construction products (ENs and ETAs)
• Facilitate the exchange of construction works and services
• To provide a set of common design standards to serve as reference documents as a means to prove compliance of buildings and civil engineering works with the Essential Requirements regarding mechanical resistance, stability and safety in the EU’s Construction Products Directive and hence with national building regulations
Benefits of the Eurocodes and Eurocode 7

- Facilitate the exchange of construction services between Member States
- Serve as a common basis for research and development in the construction sector
- Allow the preparation of common design aids and software
- Increase the competitiveness of the European civil engineering firms, contractors, designers and product manufacturers in their world-wide activities
- As part of the harmonised set of Eurocodes, Eurocode 7
  - Harmonising geotechnical designs in different countries and
  - Harmonising geotechnical design with structural design
Development of Eurocodes and Eurocode 7

• 1974 – Initiative by for Eurocodes by universities and profession
• 1975 – CEC decided on an action programme for the Eurocodes
• 1980 – Niels Krebs Ovesen appointed chairman of ISSMGE sub-committee for Eurocode 7
• 1981 – First EC7 committee meeting
• 1987 – Model Eurocode 7 produced
• 1990 – Work transferred from CEC to CEN
• 1994 – ENV (trial) trial version of Eurocode 7 published by CEN
• 2004 – EN (European Standard) version of Eurocode 7 Part 1
• 2007 – EN version of Eurocode 7 Part 2
• 2010 – Implementation of Eurocode 7 and other Eurocodes

• **29 years** from 1st committee meeting to implementation
A Structure Designed to Eurocode 7

Øresund Bridge
Linking Denmark and Sweden – Copenhagen to Malmö
Eurocode Design Method

- All the Eurocodes are all based on a common design method
- The common design method is presented in EN 1990
- A common loading code for all the Eurocodes is presented in EN 1991- Actions
- The Eurocodes share a common terminology and symbols
- The common design method for the verification of safety and serviceability involves
  - The limit state design method
  - Partial factors
  - Characteristic actions and material parameters or resistances
  - Reliability based
3 Challenges in Preparing Eurocode 7

To prepare a geotechnical standard that:

1. Harmonised geotechnical design with structural design
   - Be consistent with design method in EN 1990
   - Use partial action factors in EN 1990
   - Provide partial material and resistance factors for soil
   - Define the characteristic value of a geotechnical parameter

2. Took account of special features of soil and geotechnical design

3. Was acceptable to European geotechnical engineers
   - Took account of different national design practices
Consistent with EN 1990

- EN 1990 originally drafted for structural designs involving manufactured materials, such as steel.
- Except in Denmark, when work started on Eurocode 7 there was no experience in Western Europe in the use of the limit state design method in geotechnics.
- Many geotechnical engineers not happy with applying the probability based design method in EN 1990 to geotechnical design.
- Use of a statistical approach and definition of 5% fractile to select characteristic value of a geotechnical parameter was not considered to be appropriate.
- In geotechnical design uncertainty in the loads, particularly loads due to self weight of soil, is much less than uncertainty in soil parameter values. Hence partial factor of 1.35 in EN 1990 considered inappropriate for many design situations, e.g. slope stability.
Scope of Eurocode 7

- Many existing codes are for a particular type of structure, e.g. foundations
- Eurocodes are for the design of all types of structures, thus Eurocode 7 covers design of foundations, piles, retaining structures, slopes, etc.
- Eurocodes include only standards for design, not for testing materials
- Since soil is a natural material, unlike other structural materials which are manufactured and the properties are specified, the selection of ground properties is a key part of the geotechnical design process
- Hence Krebs Ovesen successfully argued with the Eurocode Steering Committee for the scope of Eurocode 7 to include requirements for ground investigations and the evaluation of geotechnical parameters
- Hence there are two parts of Eurocode 7:
  - Part 1: General rules
  - Part 2: Ground investigation and testing
Nature of Eurocode 7

- Eurocode 7 differs from the other Eurocodes because:
  - Soil is a natural material, and
  - Different soils and climatic conditions in different European countries

- Determination of geotechnical parameters is part of design process and the importance of geotechnical investigations and testing is emphasised

- Different testing methods and calculation models in the different countries

- Hence Eurocode 7 is not a prescriptive code but focuses on the design principles, giving:
  - The equilibrium equations to be satisfied
  - How to select parameter values
  - How to apply the safety elements (e.g. partial factors)
  - Factors to be considered in design

- Unlike the Eurocodes for structural design, no calculation models are provided in the code text of Eurocode 7
Eurocode 7: Part 1 - Code text

• EN 1997-1: *Geotechnical design - Part 1: General rules* provides the general rules for geotechnical design. It is an umbrella design code.
• Relevant to all geotechnical design situations.
• Has following 12 sections:
  1. General
  2. Basis of geotechnical design
  3. Geotechnical data
  4. Supervision of construction, monitoring and maintenance
  5. Fill, dewatering, ground improvement and reinforcement
  6. Spread foundations
  7. Pile foundations
  8. Anchorages
  9. Retaining structures
  10. Hydraulic failure
  11. Overall stability
  12. Embankments

• EN 1997-1 is **only** concerned with *geotechnical design*. It does not provide requirements for testing or construction (execution).
• EN 1997-1 refers to CEN standards – e.g. pile and anchorage testing.
Eurocode 7: Part 1 - Annexes

- EN 1997-1 has following 9 annexes
  A. (normative) Partial and correlation factors for ultimate limit states and recommended values Basis of geotechnical design
  B. (informative) Background information on partial factors for Design Approaches 1, 2 and 3
  C. (informative) Sample procedures to determine limit values of earth pressures on vertical walls
  D. (informative) A sample analytical method for bearing resistance calculation
  E. (informative) A sample semi-empirical method for bearing resistance estimation
  F. (informative) Sample methods for settlement evaluation
  G. (informative) A sample method for deriving presumed bearing resistance for spread foundations on roc Retaining structures
  H. (informative) Limiting values of structural deformation and foundation movement
  J. (informative) Checklist for construction supervision and performance monitoring

- Only Annex A is normative – i.e. mandatory
- All other Annexes B to J are informative – i.e. optional
- Calculation models are in the annexes
Eurocode 7: Part 2 - Code Text

• EN 1997-2: *Geotechnical design - Part 2: Ground investigation and testing* provides rules supplementary to EN 1997-1 related to:
  – Planning and reporting of ground investigations
  – General requirements for a number of commonly used laboratory and field tests
  – Interpretation and evaluation of test results
  – Derivation of values of geotechnical parameters and coefficients

• EN 1997-2 has the following 6 sections:
  1. General
  2. Planning of ground investigations
  3. Soil and rock sampling and groundwater measurements
  4. Field tests in soil and rock
  5. Laboratory tests on soil and rock
  6. Ground investigation report

• Part 2 is a design standard, NOT a standard for laboratory or field tests
• EN 1997-2 refers to many CEN standards for ground investigations and testing methods
Eurocode 7: Part 2 – Annexes (1)

- EN 1997-2 has 23 annexes
- All the annexes are informative
- Annex A provides information on the test results obtained from different tests
- Annexes D to K provide information on 8 different field tests
  A. (informative) List of test results of geotechnical test standards
  B. (informative) Planning of geotechnical investigations (informative)
  C. (informative) Example of groundwater pressure derivations based on a model and long term measurements
  D. (informative) Cone and piezocone penetration tests
  E. (informative) Pressuremeter test
  F. (informative) Standard penetration test
  G. (informative) Dynamic probing test
  H. (informative) Weight sounding test
  I. (informative) Field vane test
  J. (informative) Flat dilatometer test Example of correlations between $E_{OED}$ and DMT results
  K. (informative) Plate loading test
Eurocode 7: Part 2 – Annexes (2)

• Annexes L to X provide guidance for the laboratory testing of soil and rock
• Annexes L and T provide guidance for sample preparation
• Annexes M and U provide guidance for the classification of soil and rock
• Annexes N to S and V and W provide guidance for 6 soil and 2 rock tests
  L. (informative) Detailed information on preparation of soil specimens for testing
  M. (informative) Detailed information on tests for classification, identification and description of soil
  N. (informative) Detailed information on chemical testing of soil
  O. (informative) Detailed information on strength index testing of soil
  P. (informative) Detailed information on strength testing of soil
  Q. (informative) Detailed information on compressibility testing of soil
  R. (informative) Detailed information on compaction testing of soil
  S. (informative) Detailed information on permeability testing of soil
  T. (informative) Preparation of specimen for testing on rock material
  U. (informative) Classification testing of rock material
  V. (informative) Swelling testing of rock material
  W. (informative) Strength testing of rock material
  X. (informative) Bibliography
Format of the Eurocodes

- The clauses in the Eurocodes are divided into Principles and Application Rules.
- The Principles comprise:
  - General statements and definitions for which there is no alternative.
  - Requirements and analytical models for which no alternative is permitted unless specifically stated.
- Principles are preceded by the letter P and have the verb “shall”.
- Application Rules are examples of generally recognised rules, which follow the Principles and satisfy their requirements and have the verb “should”.
  - It is permissible to use alternatives to the Application Rules given in Eurocode 7, provided it is shown that the alternative rules accord with the relevant Principles and are at least equivalent with regard to the structural safety, serviceability and durability.
  - NOTE: If an alternative design rule is submitted for an application rule, the resulting design cannot be claimed to be wholly in accordance with EN 1997-1, even though the design will remain in accordance with the Principles of EN 1997-1.
Assumptions

• Eurocode 7, like the other Eurocodes is based on the following important assumptions:
  – Data required for design are collected, recorded and interpreted by appropriately qualified personnel
  – Structures are designed by appropriately qualified and experienced personnel
  – Adequate continuity and communication exist between the personnel involved in data-collection, design and construction
  – Adequate supervision and quality control are provided in factories, in plants, and on site
  – Execution is carried out according to the relevant standards and specifications by personnel having the appropriate skill and experience
  – Construction materials and products are used as specified in this standard or in the relevant material or product specifications
  – The structure will be adequately maintained to ensure its safety and serviceability for the designed service life
  – The structure will be used for the purpose defined for the design
• These assumptions need to be considered by the designer and the client
• To prevent uncertainty, compliance with them should be documented, e.g. in the geotechnical design report
• These assumptions are leading to the establishment of registers of geotechnical engineers
References


• *Decoding Eurocode 7* by Bond A and Harris A, 2008

• *Geotechnical Design to Eurocode 7* by Orr T.L.L. and Farrell E.R., Springer, 1999 (out of print)

• *Proceedings of International Workshop on the Evaluation of Eurocode 7*, Dublin March/April 2005, ed. T. Orr, Department of civil Engineering, Trinity College Dublin
Discussion

Any questions?
Session 1b

Basis of Design

and

Main Features of Eurocode 7
**Basis of Design and Basic Requirements**

- Basis of design for all the Eurocodes is given in EN 1990
- The Basic Requirements regarding safety and serviceability to be satisfied by all structures designed to the Eurocodes are given as Principles in EN 1990

2.1(1)P A structure shall be designed and executed in such a way that it will, during its intended life, with appropriate degrees of reliability and in an economical way
  - Sustain all actions and influences likely to occur during execution and use, and
  - Remain fit for the use for which it is required

2.1(2)P A structure shall be designed to have adequate
  - Structural resistance
  - Serviceability, and
  - Durability
Achieving Basic Requirements

Application Rule in EN 1990

2.1(6) The basic requirements should be met:

– By the choice of suitable materials
– By appropriate design and detailing, and
– By specifying control procedures for design, production, execution, and use relevant to the particular project

Section 2.2 Reliability Management in EN 1990

2.2(1)P The reliability required for structures within the scope of EN 1990 shall be achieved

a) By design in accordance with EN 1990 to EN 1999 and
b) By

– Appropriate execution and
– Quality management measures
Geotechnical Design Process in Eurocode 7

- To satisfy the EN 1990 basic requirements, Chapter 2 of Eurocode 7 Part 1 (EN 1997-1), called Basis of Geotechnical Design, provides the basis for geotechnical designs
- Eurocode 7 provides the requirements for the entire geotechnical design process
- Geotechnical design process involves 6 stages
  - Assessing the geotechnical complexity and risk
  - Specifying ground investigations
  - Determining and selecting geotechnical parameter values
  - Using verification (design) methods
  - Monitoring during construction – checking ground conditions
  - Specifying requirements for maintenance of completed structure after construction
Identifying the Complexity and Risk

• 2.1(8)P In order to establish minimum requirements for the extent and content of geotechnical investigations, calculations and control checks, the complexity of each geotechnical design shall be identified together with the associated risks. In particular, a distinction shall be made between:
  – Light and simple structures and small earthworks for which it is possible to ensure that the minimum requirements will be satisfied by experience and qualitative geotechnical investigations, with negligible risk
  – Other geotechnical structures

Note: The manner in which these minimum requirements are satisfied may be given in the National Annex

• The complexity of a geotechnical design can vary greatly from very simple to very complex, design situations
Assessing the Complexity

• Factors to be taken into account when assessing the complexity of a geotechnical design are:
  – Ground conditions
  – Groundwater conditions
  – Regional seismicity
  – Influence of the environment
  – Nature and size of the structure
  – Conditions with regard to the surroundings

• Provisions for assessing the complexity of geotechnical design situations and for addressing the geotechnical risks are an important and innovative feature of Eurocode 7
2.1(10) To establish geotechnical design requirements (associated with the complexity), three Geotechnical Categories, 1, 2 and 3, may be introduced.

- **GC1**
  - Small relatively simple structures on ground conditions which are known from experience to be straightforward and do not involve soft, loose or compressible soil, loose fill or sloping ground.

- **GC2**
  - Conventional types of structures and foundations with no exceptional risk or difficult ground or loading conditions.

- **GC3**
  - Very large structures on unusual or exceptionally difficult ground conditions requiring non-routine investigations and tests.

- **Note**: The Geotechnical Categories are in an Application Rule, not a Principle clause, and so are optional.
The Limit State Method in Eurocode 7

• For each geotechnical design it shall be verified that no relevant limit state (failure mode), as defined in EN 1990:2002, is exceeded (Cl 2.1(1)P)

• Need to check that the occurrence of both an ultimate limit state (ULS) and a serviceability limit state (SLS) is sufficiently unlikely

• Designs need to be checked for all relevant limit states

• Designs may be verified (checked) using **one or more of the following:**
  – Calculations
  – Prescriptive measures
  – Experimental models and load tests, and
  – An observational method

• Calculations are carried out using design values obtained by applying partial factors to characteristic loads and characteristic material parameters or resistances
Ultimate Limit States

- Eurocode 7 defines 5 Ultimate Limit States (Cl. 2.4.7.1):
  - **EQU**: Loss of equilibrium of the structure or the ground considered as a rigid body, in which the strength of structural properties and the ground are insignificant in providing resistance
  - **STR**: Internal failure or excessive deformation of the structure or structural elements, including e.g. footings, piles or basement walls, in which the strength of structural materials is significant in providing resistance
  - **GEO**: Failure or excessive deformation of the ground, in which the strength of soil of rock is significant in providing resistance
  - **UPL**: Loss of equilibrium of the structure of the ground due to uplift by water pressure (buoyancy) or other vertical actions
  - **HYD**: Hydraulic heave, internal erosion and piping in the ground caused by hydraulic gradients
• GEO is the relevant ultimate limit state for most geotechnical designs involving shear strength failure in the ground

• Should also consider other ultimate limit states

• Different sets of partial factors are provided for each ultimate limit state, UPL, GEO/STR, EQU and HYD

• Normally a failure analysis with strength parameters is used to check a ULS and a separate deformation analysis with stiffness parameters is used to check an SLS (Direct Method)

• In the case of spread foundations, Eurocode 7 permits the use of an indirect method, whereby using comparable experience and the results of field or laboratory measurements or observations, calculations for one limit state, e.g. the ULS, may used so as to satisfy the requirements of all relevant limit states
Actions and Resistances

- An action is defined in EN 1990 as:
  - a) Set of forces (loads) applied to the structure (direct action)
  - b) Set of imposed deformations or accelerations caused for example, by temperature changes, moisture variation, uneven settlement or earthquakes (indirect action)

- A geotechnical action is defined in EN 1997-1 as:
  - action transmitted to the structure by the ground, fill, standing water or groundwater

- A resistance is defined as:
  - capacity of a component, or cross-section of a component of a structure to withstand actions without mechanical failure e.g. resistance of the ground, bending resistance, buckling resistance, tensile resistance

- Note:
  - A geotechnical action may involve soil strength as well as weight terms, e.g. active earth pressure
  - A geotechnical resistance may involve weight as well as soil strength, e.g. bearing resistance
Partial Factors

• Sets of partial factors are required for each Ultimate Limit State
• Partial factors are grouped into sets in Annex A
  – A for partial factors on actions or effects of actions
  – M for partial factors on soil parameters
  – R for partial factors on resistances
• Partial factors for Serviceability Limit States, e.g. on loads and on soil stiffness or compressibility, are all equal to unity
• Since soil is a frictional material, the weight of the soil is both a load and contributes to the shearing resistance
• Hence the partial material factor value on the self weight of soil is unity
• Similarly a partial action factor of unity is often adopted for permanent loads
Geotechnical Design Components

- Geometry
- Ground properties
- Actions (loads)
- Calculation models
  - All relevant limit states
  - ULS and SLS
- Safety and serviceability elements
  - Partial factors
  - Limiting values of deformations
ULS Design Equations

• For each ultimate limit state, Eurocode 7 provides the relevant equilibrium equation that has to be satisfied

• For GEO/STR limit states, the equilibrium equation is:

\[ E_d \leq R_d \]

where

- \( E_d \) = design value of the effect of an action, and
- \( R_d \) = design resistance

• \( E_d \) is a function of loads and sometimes soil strength \( f(G, Q, c_u, c', \tan \phi') \)

• \( R_d \) is a function of soil strength and sometimes loads \( f(c_u, c', \tan \phi', G, Q) \)

• Note that \( E_d \) and \( R_d \) are forces, not stresses or pressures as in traditional geotechnical designs, e.g. bearing pressure

• Similar equilibrium equations are given for the three other ULSs

• No calculation models for \( E_d \) or \( R_d \) given in code text, only in Annexes, e.g. for earth pressure (C) and bearing resistance (D)
SLS Design Equation

- The equation to be satisfied in the case of serviceability limit states is:

\[ E_d \leq C_d \]

where:
- \( E_d \) = design value of the effect of actions, e.g. settlement, and
- \( C_d \) = limiting design value of the effect of an action

- No calculation models for \( E_d \) are given in the code text and no values are given for \( C_d \)

- However, some sample methods for settlement evaluation are given in Annex E and some suggested limiting values of structural deformation and foundation movement are given in Annex H
Checklists

- Many checklists are provided in Eurocode 7
- Checklists are lists of factors or features to be considered or taken into account with regard to the different aspects of a geotechnical design
- Checklists are key components of Eurocode 7
- They embody the principles of Eurocode 7 and provide a framework to focus attention on the essential factors and features
Example of a Checklist

<table>
<thead>
<tr>
<th>Reference</th>
<th>Factors to be considered</th>
<th>Considered</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>General suitability of the ground on which the structure is located</td>
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<tr>
<td>2.</td>
<td>Disposition &amp; classification of relevant zones of soil and rock</td>
<td></td>
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<td>3.</td>
<td>Mine workings, caves and other underground works</td>
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<td>4.</td>
<td>For structures resting on or near rock:</td>
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<td></td>
<td>• dipping bedding planes</td>
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<td></td>
<td>• interbedded hard and soft strata</td>
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<td></td>
<td>• faults, joints and fissures</td>
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<td></td>
<td>• solution cavities and swallow holes filled with soft material</td>
<td></td>
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<tr>
<td>5.</td>
<td>The actions and their combinations</td>
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<tr>
<td>6.</td>
<td>The nature of the environment including:</td>
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<td></td>
<td>• the effects of scour, erosion and excavation on the geometry of the ground surface</td>
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<td>• the effects of chemical corrosion</td>
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<td>• the effects of weathering</td>
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<td></td>
<td>• the effects of freezing</td>
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<tr>
<td>7.</td>
<td>Variation of groundwater levels including effects of dewatering, flooding and the failure of drainage systems</td>
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<tr>
<td>8.</td>
<td>The presence of gases emerging from the ground</td>
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<tr>
<td>9.</td>
<td>Other effects of time and the environment on the properties of materials</td>
<td></td>
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<tr>
<td>10.</td>
<td>Construction sequence (not actually included in C2.2)</td>
<td></td>
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<tr>
<td>11.</td>
<td>Earthquake hazard</td>
<td></td>
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<tr>
<td>12.</td>
<td>Subsidence due to mining and other causes</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>The tolerance of the structure to deformations</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>The effects of the new structure on existing structures and services</td>
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</tbody>
</table>

Factors to be considered when specifying a design situation (Orr & Farrell, 1998)

Definition of design situation:
Design situations are the circumstances in which the structure may be required to fulfil its function. The selected design situations should be sufficiently severe and so varied as to encompass all conditions which can reasonably be foreseen to occur during the execution and use of the structure.
Observation and Evaluation

• Eurocode 7 stresses the importance of observation in geotechnical design

• There is a separate section 12 on the Supervision of Construction, Monitoring and Maintenance

• Emphasis is also place on evaluation

• This word occurs frequently in Section 3 in relation to the assessment of geotechnical parameter values and the interpretation of tests results
Geotechnical Design Report

• Eurocode 7 requires that a Geotechnical Design Report shall be prepared

• The Geotechnical Design Report will normally include the following:
  – A description of the site and surroundings
  – A description of the ground conditions
  – A description of the proposed construction, including the loads and limiting movements
  – Design values of the soil and rock properties
  – Statements on the codes and standards applied
  – Statements on the level of acceptable level of risk
  – Geotechnical design calculations, assumptions made and design results and drawings
  – A list of items to be checked during construction or requiring maintenance or monitoring after construction
Ground Investigation Report

• Eurocode 7 requires that the geotechnical information is presented in a Ground Investigation Report

• A Ground Investigation Report should normally consist of two parts:
  – One part which presents all the available geotechnical information – i.e. a factual report
  – A second part which provides a geotechnical evaluation of the information, stating the assumptions made in the interpretation of the test results – i.e. an interpretative report
  – This information may be presented as one report or as separate parts

• A Ground Investigation Report should form part of the Geotechnical Design Report
Session 1c

Geotechnical Investigations
and
Geotechnical Data
Eurocode 7 - Part 1

- Eurocode 7 Part 1 - Section 3: Geotechnical Data of provides the general requirements for:
  - The **geotechnical investigations**
  - The **collection of geotechnical data**
  - The **evaluation** of geotechnical parameters
  - The **selection** of characteristic parameter values
  - The **presentation** of geotechnical information
Eurocode 7- Part 2

• EN 1997-2: Geotechnical design - Part 2: Ground Investigation and Testing provides rules supplementary to Part 1 on:
  – Planning and reporting of ground investigations
  – General rules and requirements for a number of commonly used laboratory and field tests
  – Interpretation and evaluation of test results
  – Derivation of values of geotechnical parameters and coefficients

• EN 1997-2 refers to many CEN standards for ground investigations and testing methods
Geotechnical Investigations

• Eurocode 7 stresses the importance of geotechnical investigations in geotechnical design (Clause 2.4.1(2))
  – *It should be considered that knowledge of the ground conditions depends on the extent and quality of the geotechnical investigations. Such knowledge and the control of workmanship are usually more significant than is precision in the calculation models or the partial factors*

• One of most important clauses in Eurocode 7

• Requirements for ground investigations are provided in Parts 1 and 2

• Part 1 states (3.2.1(1))
  – *Geotechnical investigations shall provide sufficient data concerning the ground and the ground-water conditions at and around the construction site for a proper description of the essential ground properties and a reliable assessment of the characteristic values of the ground parameters to be used in design calculations*
Types of Geotechnical Investigations

• Eurocode 7 Part 1 provides general requirements for 2 types of investigations

• Preliminary investigations (*Clause 3.2.2(1)*)
  – Assess the general suitability of the site
  – Compare alternative sites, if relevant
  – Estimate the changes that may be caused by the proposed works
  – Plan the design and control investigations, including identification of the extent of ground, which may have significant influence on the behaviour of the structure
  – Identify borrow areas, if relevant

• Design investigations (*Clause 3.2.3(1)*)
  – Provide the information required for an adequate design of the temporary and permanent works
  – Provide the information required to plan the method of construction
  – Identify any difficulties that may arise during construction
Requirements for Geotechnical Investigations

- Part 2 provides specific requirements for geotechnical investigations.
- The locations of investigation points and the depths of the investigations shall be selected on the basis of the preliminary investigations as a function of the geological conditions, the dimensions of the structure and the engineering problem involved (Clause 2.1.4.3(1)).
- The investigation points for a building or structure should be placed at critical points relative to the shape, structural behaviour and expected loading distribution (e.g. at the corners of the foundation area) (Clause 2.1.4.3(2)).
- For the spacing of investigation points and investigation depths, the values given in B.3 can be used as guidance (Clause 2.1.4.3 Note).
Planning of Geotechnical Investigations
Spacing of Boreholes

EN 1997-2: Annex B

- The following spacing of investigation points should be used as guidance:
  - For high-rise and industrial structures, a grid pattern with points at 15 m to 40 m distance;
  - For large-area structures, a grid pattern with points at not more than 60 m distance;
  - For linear structures (roads, railways, channels, pipelines, dikes, tunnels, retaining walls), a spacing of 20 m to 200 m;
  - For special structures (e.g. bridges, stacks, machinery foundations), two to six investigation points per foundation;
  - For dams and weirs, 25 m to 75 m distance, along relevant sections.
Planning of Geotechnical Investigations
Depth of Boreholes

- For high-rise structures and civil engineering projects, the larger value of the following conditions should be applied (see Fig B.1 a)):
  - \( z_a \geq 6 \text{ m} \)
  - \( z_a \geq 3,0b_F \)

where \( b_F \) is the smaller side length of the foundation.

- For raft foundations and structures with several foundation elements whose effects in deeper strata are superimposed on each other:
  - \( z_a \geq 1,5b_B \)

where \( b_B \) is the smaller side of the structure (see Fig. B.1 b))

- \( z_a \) is the lowest point of the foundation of the structure or structural element, or the excavation base. Where more than one alternative is specified for establishing \( z_a \), the one which yields the largest value should be applied.

- Greater investigation depths should always be selected, where unfavourable geological conditions, such as weak or compressible strata below strata of higher bearing capacity, are presumed.
Planning of Geotechnical Investigations
Depth of Boreholes

- $z_a$ is the lowest point of the foundation of the structure or structural element, or the excavation base. Where more than one alternative is specified for establishing $z_a$, the one which yields the largest value should be applied.

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- For raft foundations and structures with several foundation elements whose effects in deeper strata are superimposed on each other:
  - $z_a \geq 1,5b_B$
  where $b_B$ is the smaller side of the structure (see Fig. B.1 b))
Determination of Soil Parameter Values and Selection of Characteristic Values
Stages to Obtain a Characteristic Value

In general 4 stages are involved

From field/lab. tests

Obtained by theory, correlation or empiricism from test results

Measured values

Derived values

Geotechnical parameter values
Quantified for design calculations

Characteristic value

From pile load tests
Derived Value

Definition

• “Value of a geotechnical parameter obtained from test results by theory, correlation or empiricism”

(EN 1997-2: Clause 1.5.3.1)

Examples

• The Annexes for the sections of Eurocode 7, Part 2 for different types of field and laboratory tests provide theories, correlation equations and graphs, to obtain derived parameter values from test results

• An example is the following equation given in Clause D2(2) of Annex D of Part 2 to obtain $\phi'$ from the results of a CPT test:

$$\phi' = 13.5 \times \log q_c + 23$$
Geotechnical Parameter Value

• Values obtained from test results and other data shall be interpreted appropriately for the limit state considered (EN 1997-1: Clause 2.4.3(2)P)

• Account shall be taken of the possible differences between the ground properties and geotechnical parameters obtained from test results (derived values) and those governing the behaviour of the geotechnical structure (EN 1997-1: Clause 2.4.3(3)P)

• The value of each geotechnical parameter should be compared with relevant published data and local and general experience (EN 1997-1: Clause 2.4.3(5))

• Geotechnical parameter values governing the behaviour of a geotechnical structure may differ from derived values due to a number of factors listed in Eurocode 7 (EN 1997-1: Clause 2.4.3(4))
Difference between Derived and Governing Geotechnical Parameter Values

Reasons for difference between derived geotechnical parameter values and values governing behaviour of geotechnical structure (Clause 2.4.3(3))

- Many geotechnical parameters are not constants but depend on stress level and mode of deformation
- Soil and rock structure (e.g. fissures, laminations, or large particles) that may play a different role in the test and in the geotechnical structure
- Time effects
- Softening effect of percolating water on soil or rock strength
- Softening effect of dynamic actions
- Brittleness or ductility of the soil and rock tested
- Method of installation of the geotechnical structure
- Influence of workmanship on artificially placed or improved ground
- Effect of construction activities on the ground properties
Factors to be Considered when Establishing Geotechnical Parameter Values

• When establishing values of geotechnical parameters, the following should be considered (EN 1997-1: Clause 1:2.4.3(5))
  – Published and well recognised information relevant to the use of each type of test in the appropriate ground conditions
  – The value of each geotechnical parameter compared with relevant published data and local and general experience
  – The variation of the geotechnical parameters that are relevant to the design
  – The results of any large scale field trials and measurements from neighbouring constructions
  – Any correlations between the results from more than one type of test;
  – Any significant deterioration in ground material properties that may occur during the lifetime of the structure
Characteristic Value in EN 1990

• EN 1990 states:
  – the characteristic value corresponds to a specified fractile of the assumed statistical distribution of the particular property
  – the characteristic value should be defined as the 5% fractile

• Above definition is not considered to be appropriate for geotechnical design because
  – It assumes the results of an unlimited test series are available
  – The 5% value of a test series represents the field behaviour of the structure
  – Soil failures are controlled by the mean value on failure surface
  – Volume of soil tested much less than that involved in a failure
  – Hence strength based on mean of test results, not 5% fractile

• For the above reasons, the drafters of Eurocode 7 were concerned that a purely statistical definition of the characteristic value is not appropriate for geotechnical design, hence an alternative definition was sought
Characteristic Value in Eurocode 7

Definition (Principle)

• *The characteristic value shall be selected as a cautious estimate of the value affecting the occurrence of the limit state*

*(EN 1997-1: Clause 2.4.5.2(2)P)*

Application Rule

• *The zone of ground governing the behaviour of a geotechnical structure at a limit state is usually much larger than a test sample or the zone of ground affected in an in situ test. Consequently the value of the governing parameter is often the mean of a range of values covering a large surface or volume of the ground. The characteristic value should be a cautious estimate of this mean value*

*(EN 1997-1: Clause 2.4.5.2(7))*

Innovative Feature

• Guidance on how to select the value of a geotechnical parameter for use in geotechnical design is an innovative feature in Eurocode 7
Selection of Characteristic Value

• The selection of characteristic values for geotechnical parameters shall take account of the following: (EN 1997-1: Clause 2.5.4.2(4)P)
  – Geological and other background information, such as data from previous projects;
  – The variability of the measured property values and other relevant information, e.g. from existing knowledge;
  – The extent of the field and laboratory investigation;
  – The type and number of samples;
  – The extent of the zone of ground governing the behaviour of the geotechnical structure at the limit state being considered;
  – The ability of the geotechnical structure to transfer loads from weak to strong zones in the ground.
Calibration and Correlation Factors

• Calibration factors shall be applied where necessary to convert laboratory or field test results according to EN 1997-2 into values that represent the behaviour of the soil and rock in the ground, for the actual limit state, or to take account of correlations used to obtain derived values from the test results (EN 1997-1: Clause 2.4.3(6)P)

• Example of correlation factors:
  • $\zeta$ factors to derive characteristic pile resistances from pile load test results
Stages to Obtain a Characteristic Value

In general 4 stages are involved

1. Measured values
   - From field/lab. tests
2. Derived values
   - Obtained by theory, correlation or empiricism from test results
   - From pile load tests
3. Geotechnical parameter values
   - Quantified for design calculations
   - Application of $\xi$ values
4. Characteristic value
Characteristic Value and Statistics

• If statistical methods are used, the characteristic value should be derived such that the calculated probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5% (EN 1997-1: Clause 2.5.4.2(11))
  – NOTE In this respect, a cautious estimate of the mean value is a selection of the mean value of the limited set of geotechnical parameter values, with a confidence level of 95%; where local failure is concerned, a cautious estimate of the low value is a 5% fractile

• At present it is not anticipated that statistical methods will routinely be used to select characteristic values

• Quote from ENV (trial) version of EN 1997 published in 1997
  – Statistical methods may be employed in the selection of characteristic values for ground properties. Such methods should allow apriori knowledge of comparable experience with ground properties to be taken into account for example by means of Baysian statistical methods
### Process to Obtain Design Value

#### Stages 1 - 3
Covered by:
EN 1997-1, Clauses 2.4.3 (Ground properties, 3.3 (Evaluation of geotechnical parameters) and EN 1997-2

- Theory, correlation or empiricism
- Values at particular points in the ground or locations on site where tests carried out or values from particular lab. specimens

#### Stages 4 & 5
Covered by
EN 1997-1, Clause 2.4.5.2 (Characteristic values of geotechnical parameters) and 2.4.6.2 (Design values of geotechnical parameters)

- Overall parameter value for volume of soil affecting the occurrence of the limit state

### Process Diagram

1. **Field/lab. tests**
   - Measured values
   - Derived values
   - Geotechnical parameter values
     - Quantified for design calculations

2. **Pile tests**
   - Characteristic value
   - Application of partial factor, $\gamma_M$
   - Design value
     - For use in design calculations

- Factors involved and to be considered at each stage are given; e.g.
  - Assessment of test and design conditions on parameter values
  - Relevant published data and local and general experience

- Cautious estimate taking account of:
  - Number of test results
  - Variability of ground
  - Scatter of test results
  - Particular limit state and volume of ground involved
  - Nature of structure
Examples

Selection of Characteristic Values
Example 1

Spread foundation from SPT results

\[ G_{v,k} = 1000 \text{ kN} \]
\[ Q_{v,k} = 750 \text{ kN} \]

\[ B = ? \]

\[ Q_{kh,v} = 0 \text{ to } 500 \text{ kN} \]

Example 2 from ETC 10: Eurocode7.com/etc10
Design Situation and SPT Results

Plan of site – Boreholes and Proposed Foundation

Questions:
• Are all boreholes considered equally?
• Is N constant or varying with depth?
• What is characteristic N value?
• What is characteristic $c_{u,k}$ value?
Characteristic Values Selected by Irish Engineers

• 1\textsuperscript{st} Step: Derive parameter value:
  Assumed constant with depth
  \( c_u = ? \text{ N} \)
  \( c_u = 5 \text{ N} \)

• 2\textsuperscript{nd} Step: Select characteristic value

• Examples of \( c_{uk} \) values selected by 8 pairs of Irish engineers:
  – 250 kPa
  – 200 kPa
  – 135 kPa
  – 197 kPa
  – 213 kPa
  – 147 kPa
  – 200 kPa
  – 175 kPa

Average \( c_{uk} = 190 \text{ kPa} \) selected by Irish engineers
Characteristic Values Selected by European Engineers

- First 11 responses received
  - 2 assumed constant with depth
  - 9 assumed increased with depth

- Assumptions regarding $c_u$ and $N$:
  - $c_u = 6$ N
  - $c_u = 5$ N
  - $c_u = 4.75$ N

- Examples of $c_{u,k}$ values at depth of 3m by 11 European engineers:
  - 260 kPa
  - 200 kPa
  - 120 kPa
  - 208 kPa
  - 164 kPa
  - 130 kPa
  - 200 kPa
  - 150 kPa
  - 150 kPa
  - 200 kPa
  - 180 kPa

- Average $c_{u,k} = 178$ kPa by European Engineers

- More cautious than 190 kPa by Irish engineers
Example 2
Characteristic $c_u$ value from lab. test results

Derived $c_u$ values (from lab. test results):
- Depth (m)  1.0  2.5  3.8  4.6  6.3  7.7  8.7
- $c_u$ (kPa) 49  72  76  51  77  54  78
Assume constant with depth
- Mean: \( \mu = 65.3 \text{ kPa} \)
- Standard deviation: \( \sigma = 13.3 \text{ kPa} \), CoV = 20%
- 5% fractile: \( m - 1.645 \sigma = 43.5 \text{ kPa} \)
- 95% confidence of mean: Student: \( m - t \sigma / \sqrt{N} = 55.6 \text{ kPa} \)
- Ovesen: \( m - 1.645 \sigma / \sqrt{N} = 52.2 \text{ kPa} \)
- Schneider: \( m - 0.5 \sigma = 58.7 \text{ kPa} \)
- Design value based on Schneider: \( c_{uk} / \gamma_M = 58.7/1.4 = 41.9 \text{ kPa} \)

Are values of \( m \) and \( \sigma \) obtained from laboratory tests representative of field values?
Example 3

Pile foundation designed from Pile Load tests

- 450mm diameter CFA piles
- In boulder clay
- 5 piles load tested
- Failure loads: Pile foundation
  - 1337 kN
  - 899 kN
  - 1664 kN
  - 1110 kN
  - 1253 kN
- Correlation factors applied to average and lowest of results to obtain characteristic pile resistance, $R_{c,k}$
- 95% confidence in pile resistance value calculated, $R_{95%}$
Characteristic Pile Resistances, $R_{c,k}$

$R_{c,k}$ values as ratio of pile resistance with 95% confidence level, $R_{95\%}$ were obtained using statistics and Student t values.

Characteristic pile resistance values, $R_{c,k}$ were obtained from pile load test results using Eurocode 7 $\xi$ factors.

Note: Ratio $R_{c,k} / R_{95\%}$ values are generally less than 1.0 indicating $\xi$ values give conservative designs.
Tutorial Exercise

Find characteristic value(s) for Example 1 from ETC 10:
http://www.eurocode7.com/etc10/

Spread foundation on sand with CPT data provided

To be discussed in the morning
Thank you
Discussion
Any questions?