Tomorrow’s geotechnical toolbox: EN 1997-2:202x Ground investigation

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La boîte à outils géotechnique de demain : EN1997-2:202x Reconnaissance des terrains

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ABSTRACT:
This paper presents an overview of the contents of Eurocode 7 Part 2, highlighting the major changes that are planned as its focus turns from test methods to the assessment of properties for engineering design. The motivation for this change and the anticipated type of information that will be given for each parameter is described. In addition the process for developing the ground model is discussed.

RÉSUMÉ:
Cette communication présente un aperçu du contenu de l'Eurocode 7, partie 2, en soulignant les principaux changements envisagés avec pour objectif de passer d'une organisation focalisée sur les méthodes d'essai à l'évaluation des propriétés nécessaires à la conception technique. La motivation pour ce changement et le type d'informations prévu pour chaque paramètre sont décrits. En outre, le processus de développement du modèle de terrain sera détaillé.

Keywords: Eurocodes; ground investigation; ground testing; European Standards;

1 INTRODUCTION

Following the widespread adoption of the Eurocodes, both in Europe and abroad, since their publication between 2002 and 2010, the production by CEN, the European Standards Organization, of a second generation of the Eurocode suite has been commissioned and funded by the European Commission.

This regeneration extends to Eurocode 7 Part 2 *Ground investigation and testing*, which – although it was published in 2007 – only came into widespread use in 2010. The revision of Part 2 is now well under way, under the direction of CEN Technical Committee TC250/SC7. This paper presents the new content of the standard and examples of the approaches being used in its re-drafting.

Preliminary work by SC7's Project Team 1 on the revision of EN 1997-2:2007 followed the guidance given by SC7 at its Leuven meeting in April 2016. A significant modification of the current structure of the code was proposed by SC7 and subsequently approved by the National Standards Bodies of CEN. The decision was made to abandon the current structure of Part 2, which is focussed on data collection methods for laboratory and field data, and instead focus on obtaining ground properties of engineering interest (such as physico-chemical properties, strength, and stiffness). The aim is to improve the everyday usefulness of the code for practitioners.

The redraft is therefore identifying the parameters that are required to design geotechnical structures and presenting the range of test methods that are suitable for determining those parameters. The new text will encourage the use of a variety of direct test methods or indirect derivations from different tests to enhance robustness in ground characterisation and in geotechnical model calibration. To this end, guidance on empirical correlations or approriate transformation between test outputs and ground parameters will be provided wherever possible.

Developing this modified structure into practical code instructions and recommendations, while avoiding textbook content and overlap with other standards (particularly geotechnical testing standards) requires an implicit acceptance of many underlying concepts that are not possible to spell out within the code itself.

Particular topics which EN 1997-2:2007 does not cover include the ground model, rock engineering, the use of geophysics in investigation, soil stiffness, dynamic response, thermal properties, and the personnel authorized to carry out investigations. The changes to accommodate these topics in the 202x revision are summarised in this paper.

2 GROUND MODEL

The level of detail of the Ground Model should be consistent with the Geotechnical Category of the structure, as established from the desk study, site re-connaissance, and ground investigations.

The Ground Model should be developed in stages starting as soon as the site is identified. At the **initial stage**, the amount of information is limited and may be largely non site-specific but could include published information, previous experience, and any other information to form a low resolution, initial (i.e. conceptual) Ground Model. This model will then be **informed** by carrying out the **desk study and site reconnaissance** before the investigation programme is designed to identify likely ground related hazards.

The desk study should comprise a systematic and comprehensive review of existing information about the site and its environs, including the geology, groundwater conditions, previous uses of the site, and prior knowledge about the characteristics of the ground. The site reconnaissance may include geological or geomorphological mapping, shallow intrusive investigation and geophysical surveying to map the geological conditions.

The Ground Model is then used to identify what is known about the site, what is not known, and what needs to be known. From this, a proposal for the investigations that are necessary can be compiled, which will usually include intrusive methods with field and laboratory testing. Each ground investigation campaign should be planned taking into account the Ground Model existing at that stage and uncertainties in that model and the zone of influence of the structure as given in EN 1997-3:202x. This cycle of using the Ground Model to identify questions that need to be addressed, planning further investigations, and then incorporating those results into the model will allow the model to evolve to the **detailed model**.

The Ground Model should include identification of the geotechnical units that make up the ground succession, an indication of the **geological structure**, and an initial understanding of the groundwater regime. The materials seen in the site reconnaissance and the preliminary investigations will have been **described and classified** in accordance with the EN ISO 14688 and 14689 standards. This description will include description of the discontinuities present in different ground units.

The ground model is then developed into the Geotechnical Design Model with parameters and taken forward by the designers who need to obtain characteristic values, as described in EN 1997-1:202x and EN 1997-3:202x. The Ground Model and the Geotechnical Design Model should be maintained and continuously evolved together as the design and construction proceeds.

3 PLANNING GROUND INVESTIGATIONS

Ground investigations should provide a description of the ground conditions relevant to the proposed works and establish a basis for the assessment of the geotechnical parameters relevant for all construction stages. The phased investigation should provide a progressive improvement in the quality and resolution of ground information and a progressive reduction in uncertainty about the ground – and therefore the risk posed by the ground.

This improvement can be achieved by carrying out non-intrusive techniques, at least initially, such as mapping (including such as geological or geomorphological) and geophysical surveying. This will usually be followed by intrusive investigation where holes are made in the ground. The approach to intrusive investigations can be by:

- progressive increase in the cost, sophistication, and depth of investigation; or
- carrying out initial (possibly deeper) holes specifically to elucidate the geology; or
- forming holes to allow access for geotechnical testing of the ground in situ and for recovery of samples for laboratory testing; or
- by progressive improvement in the targeting of the investigation to provide information for the design.

Ground investigations shall provide data concerning the ground and the groundwater conditions at and around the construction site for a proper description of the required ground properties and a reliable assessment of the characteristic values of the ground parameters to be used in design calculations.

Investigation of the ground and obtaining of parameters should take account of the variability of the ground including lateral and vertical variability of the conditions with respect to the scale of the structure.

3.1 Personnel involved in ground investigations

Those involved with ground investigations should be suitably qualified and experienced for the tasks being carried out. This builds on the text in EN 1997-1:202x by specifically considering those persons planning, carrying out, reporting, and evaluating the results of the ground investigation. The requirements are set out in a Normative Annex which identifies the requirements for those designing and reporting investigations, lead operators (drillers) and field and laboratory technicians.

At all stages, the evaluation and interpretation of the results of any aspect of investigation should be checked by a competent person, who is familiar with the earlier stages of the investigation and the design.

3.2 Sequencing and intensity of investigations

The stages of ground investigation that are suggested include **preliminary investigation** (with relatively widely spaced investigation points), followed by **design investigations** (mainly aimed at obtaining geotechnical parameters through testing and measurement). There should also normally be **control and monitoring investigations** continuing into the construction phase, when the ground and groundwater conditions actually encountered are verified against those predicted and assumed in the design. Monitoring of the ground at and around the site – and of the construction – may also be carried out. Details of monitoring for different geotechnical structures will be given in EN 1997-3:202x.

The results of desk studies and site reconnaissance shall be considered when selecting investigation methods and locating investigation points. Investigations shall target variation in conditions of soil, rock, and groundwater. The intensity and depth of investigation are selected on the basis of current knowledge and geological conditions and should be sufficient to identify the sequence of strata, their ease of excavation, and their strength and deformation properties over the full zone that the structure will influence. Guidance on the scale of zones of influence is given in EN 1997-3:202x and the geotechnical execution standards.

The current EN 1997-2:2007 offers informative guidance on the depth and spacing of investigation points. The coverage on investigation point spacing is being critically reviewed for inclusion in the revised EN 1997-2:202x in order to provide a baseline intensity of investigation. Recommendations on minimum depth of investigation will be moved into EN 1997-3:202x, where they can be adapted to the specific requirements of different geotechnical structures.

All possible information should be gathered on the groundwater conditions at every stage. The collection of groundwater information should continue through all stages of ground investigation, with observations both during and after the work (with the installation and reading of monitoring instruments).

3.3 *Sample Quality*

The sampling quality categories and the number of samples to be taken shall be based on:

- the aim of the ground investigation;
- the geology of the site;
- the complexity of the geotechnical structure;
- the laboratory tests that are proposed.

Three laboratory specimen quality classes and three sampling categories are considered. Sampling categories A-C are defined in EN ISO 22475-1 (see Table 1).

Class 1 laboratory specimens are effectively undisturbed with the water content, consistency, void ratio, structure (bedding and discontinuities) and chemistry essentially unchanged. Category A sampling should be used to obtain Class 1 specimens.

Class 2 laboratory specimens are disturbed. All the constituents of the in-situ soil or rock are in their original proportions and retaining the natural water content but the structure has been disturbed. The general arrangement of the different layers or components can be identified. Category A or B sampling should be used to obtain Class 2 specimens.

Class 3 laboratory specimens are remoulded with the initial properties changed by the sampling and handling; any category of sampling can be used to obtain Class 3 specimens.

3.4 *An additional Class 4 is being considered for reconstituted samples. Geophysical tests*

Geophysical tests should be used to identify:

- stratigraphy and lithology and, in particular, any lateral variations;
- natural and man-made cavities or in-filled cavities and holes;
- buried objects and artefacts that may interfere with the project;
- measurement of in situ properties.

Surface geophysics should be used to check the existence of anomalies between adjacent investigation points.

Suitability of a geophysical test should be checked according to sensitivity of the geophysical parameter to the ground characteristic being measured and according to their spatial resolution.

Soil or rock properties	**Laboratory Quality classes**		
	1	2	3
Unchanged ground properties:			
Identification of soil and rock type	x	x	x
Particle shape and mineralogy	x	x	x
Dimensions and grading of all particles	x	x	
Water content	x	x	
Density, density index, porosity, permeability	x		
Compressibility, shear strength	x		
Properties that can be determined:			
Identification of soil and rock type	x	x	x
Boundaries of strata – coarse definition	x	x	x
Boundaries of strata – fine definition	x	x	x
Water content	x	x	
Atterberg limits, vol. grains, organic matter content	x	x	
Density, density index, porosity, permeability	x	x	
Weathering			
Discontinuity description	x	x	
Discontinuity properties	x	x	
Compressibility, shear strength, stiffness (at small strain)	x x		
Sampling categories	A	A	A
		B	B
			C

Table 1 Sample quality classes

3.5 *Instrumentation and monitoring*

A range of instruments may be installed to allow monitoring of:

- groundwater conditions (piezometric levels and pressures);
- ground movements;
- strains in the ground;
- ground pressures;
- vibrations;
- other environmental conditions.

The programme of monitoring should:

- establish conditions for inclusion in design;
- determine seasonal and progressive changes with time;
- establish baseline conditions before construction;
- measure effects of construction.

The programme of monitoring should commence as early as possible in the preliminary investigation and continue through the design period into construction and post construction.

4 INTRINSIC PHYSICAL, STATE AND CHEMICAL PROPERTIES

The physical properties of soils, rock, and water are controlled by the nature and proportions of the particles, water and air present. The properties which might need to be measured are listed with the tests appropriate for their measurement. The list of tests includes the Minimum Quality Class (MQC) of sample required for each test method.

Laboratory tests available to determine the required properties include:

- Intrinsic properties:
- State properties (for strength and stiffness see below)
- Stress properties
- Compaction properties
- Chemical properties
- Groundwater chemistry

A range of different geotechnical properties can be derived from correlations with the results of other tests.

5 STRENGTH

The main failure mode of concern in the ground is failure in shear. Shear strength therefore features prominently in both soil and rock mechanics design; however, tensile strength is also significant in some cases.

Strength envelopes define the combination of stresses that produce various modes of material failure. Theyappear in various constitutive models for soil and rock (for example, the rigid-perfectly plastic models used in classical bearing capacity analysis).

More elaborate constitutive models frequently incorporate strength envelopes as an explicit limit condition (for instance, in elasto-plastic critical state models, such as Cam Clay). Even if a model does not incorporate an explicit strength envelope in its formulation, it should be able to predict failure conditions and therefore implicitly include a failure envelope.

Strength envelopes being considered for inclusion in EN 1997-2:202x include the Mohr-Coulomb and the Hoek-Brown criteria. These envelopes include consideration of tensile strength parameters, although it may be preferable to impose separate limits on tensile stress that can be factored independently from the main shear strength parameters. Such limits could be related to specific test results, such as those from Brazilian or unconfined compression tests.

The strength of joints and fissures in soil and rock can be modelled by Mohr-Coulomb parameters (c_{joint}, φ_{joint}) and likewise for interfaces between the ground and structural materials (c_{int}, φ_{int}).

Strength parameters for soils may be determined directly using any of the laboratory tests listed in the standard and through indirect derivation using the results of fall cone, cone penetration, standard penetration, pressure-meter, or dilatometer tests.

Evaluation of rock and rock-mass strength parameters may be by direct tests in the field or laboratory or by indirect derivation from other tests or through one of the approaches using rock mass classification systems.

Mohr-Coulomb parameters (hence envelopes) for a ground unit are only valid under particular conditions. This has several implications for code writing:

- Recommended design procedures in EN 1997-3:202x must include statements about assumed conditions of validity for particular envelopes to apply.
- In cases where no recommended design procedure is given, EN 1997-1:202x will require the designer to ensure that the choice of strength envelope is compatible with the conditions affecting the design situation
- Guidance given by EN 1997-2:202x about derived strength parameters from different investigation procedures must specify under which conditions the parameters derived from the test are relevant.

These considerations often apply to different stress, strain, and drainage conditions.

Mohr-Coulomb envelopes can be conceived as linear approximations of a more realistic non-linear strength envelope. Therefore, when using Mohr-Coulomb parameters, the assumed range of normal or median stresses should be stated, either in EN 1997-3:202x or by the designer.

In the case of rock mechanics the Hoek-Brown non-linear envelope has gained wide acceptance. Current proposals are that EN 1997-2:202x will include statements about evaluation of Hoek-Brown parameters from the results of ground investigations and how to relate Hoek-Brown failure envelopes to approximate Mohr-Coulomb envelopes.

Up to three different Mohr-Coulomb envelopes for a ground unit are proposed, corresponding to three different strain conditions, namely:

- A peak strength envelope, corresponding to small strain conditions, and generally represented by c_{peak}, φ_{peak}

- A critical-state strength envelope, corresponding to constant volume shearing conditions, and generally represented by c_{cs}, φ_{cs}
- A residual strength envelope, corresponding to large shearing displacements, and generally represented by c_{res}, φ_{res}

For the constant volume and residual strength envelopes, a recommended value c = 0 (zero cohesive strength) will be proposed. In most design procedures use of a single envelope may be all that is required.

For saturated fine soils in undrained conditions a total stress approach may be used advantageously. This gives rise to two possible envelopes for a given ground unit:

- An effective strength envelope, which may generally be represented by c', φ'
- A total stress envelope, which may generally be represented by the parameter c_u (with φ = 0), following common usage

6 STIFFNESS UNDER STATIC LOAD

Ground stiffness may be characterized by a complete stress-strain relation or by conventionally defined moduli over specified ranges.

Conventionally defined moduli include tangent moduli, such as the initial Young's modulus of elasticity (E_0) and secant moduli (for instance E_{50}, corresponding to the stiffness at 50 % of the maximum shear stress).

Stiffness properties may be determined directly from test results or indirectly through correlation and are to be defined for a known stress level (consolidation) and for a specific stress path.

Consolidation conditions and stress paths to be used during acquisition of stiffness parameters shall be defined in accordance with the limit state being verified (particularly for use with advanced constitutive models).

Ground stiffness can be derived based on the type of experimental results. A unique modulus corresponding to a specific loading "step" can be obtained from:

- laboratory testing: bender element tests, tests on rocks, uniaxial compression and indirect tensile strength tests;
- field (including geophysical) testing: dilatometer tests, seismic surface wave tests, cross hole tests
- correlation with standard and cone penetration tests

A modulus defined between two strain levels or over a cycle can be obtained from:

- laboratory testing: E_{oed} from oedometer, E_{50} from triaxial and unconfined compression tests
- field testing: E_M from pressuremeter tests, E_{v2} from plate loading tests

Stiffness curves (modulus as a function of strain level), from which several measures of modulus (secant, tangent, etc.) can be determined, can be obtained over different strain ranges from:

- laboratory testing: direct simple shear, triaxial, resonant column tests;
- field testing: expansion (prebored, self-boring, push-in, pressuremeter) tests

The stiffness derived from these tests for a defined confining stress can be related to shear or Young modulus either by theoretical relationships or correlation.

When determining soil and rock stiffness, factors affecting the measurement and therefore the selected test method are:

- intrinsic/state properties (density, etc.);
- scale of specimens according to ground mass;
- strain level compared to the one present in the ground;
- strain rate adapted to the limit state i.e. short term/long term, undrained/drained, ultimate/serviceability;
- dimensions of freedom.

These techniques can be combined – depending on the Geotechnical Category and the stage of the project (from Ground Model to Geotechnical Design Model) or construction –to reconstruct a stiffness degradation curve.

Stiffness parameters for soils may be determined indirectly using other tests including standard and cone penetration tests.

7 RESPONSE TO DYNAMIC LOADS

The response of soils and rocks to cyclic and dynamic loads is relevant for several applications, including:

- seismic design;
- design of foundations for cyclic loadings (e.g. winds, ocean waves, machines);

- vibrations induced by man-made activities (e.g. high-speed trains, factories, constructions).

EN 1998 *Design of structures for earthquake resistance* and – in particlar – EN 1998 Part 5 *Foundations, retaining structures and geotechnical aspects* rely on dynamic parameters of soils and rocks for the evaluation of seismic actions and for detailed design.

The second generation of Eurocode 7 Part 2 will address the failure of EN 1997-2:2007 to provide these essential parameters.

7.1 Laboratory tests

The response to cyclic loads should be investigated with laboratory tests on specimens obtained from undisturbed samples (Class 1 according to Table 1).

Care shall be exercised during soil sampling and preparation to preserve soil density and microscopic soil fabric. Specimens shall be consolidated to the in situ state of stress before applying cyclic loading. When undisturbed sampling is not feasible, the test may be performed on reconstituted samples that reproduce the state conditions (stress, density and saturation) of the soil in situ. Specimens of soil to be used for fill should be reconstructed from bulk or disturbed samples by simulating the expected compaction process to be employed on site.

Laboratory tests that can be used for dynamic testing of soils include:

- Resonant Column Test (RC)
- Cyclic Torsional Shear Test (CTST)
- Cyclic Simple Shear Test (CSST)
- Cyclic Triaxial Test (CTxT)
- Bender Element Tests (BE)

Apparatuses differ in the range of shear strains that can obtain, their frequency of excitation, and their ability to measure excess pore pressure.

Information on the operative range of different laboratory tests is reported in terms of range of induced shear strains and frequencies of excitation. The frequencies associated with earthquake ground motions are typically in the range 0.2-10 Hz.

Specimens of soil to be used for fill should be reconstructed from bulk or disturbed samples by simulating the expected compaction process to be employed on site.

7.2 Geophysical tests (seismic)

The small strain shear modulus (G_0) should be determined directly using in situ geophysical measurement of the propagation of seismic waves

Elastic wave shear and compression wave velocities can be determined directly using in situ geophysical methods listed in the standard.

For structures in Consequence Class 1 or design situations involving very low to moderate seismicity (see EN 1998-1:202x), the shear wave velocity may be determined indirectly using field tests, such as the cone and standard penetration, pressuremeter, and dilatometer tests.

8 GROUNDWATER AND HYDRAULIC CONDUCTIVITY

Groundwater investigations should provide all relevant information on groundwater needed for geotechnical design and construction, including:

- the depth, thickness, extent and conductivity of water-bearing strata in the ground;
- joint systems in the rock;
- the permeability or hydraulic conductivity of each geotechnical unit;
- the elevation of the groundwater surface or piezometric head of aquifers and their variation over time;
- actual piezometric levels including possible extreme levels and their periods of recurrence;
- the piezometric pressure distribution;
- the chemical composition and temperature of groundwater.

The type of equipment used for piezometric measurements shall be selected according to:

- the type and conductivity of ground;
- the purpose of the measurements;
- the required observation time;
- the expected groundwater fluctuations;
- the response time of the equipment and ground.

The number, location, and depth of the piezometric measurements shall be chosen considering their purpose. Requirements will be specified for field data relating to:

- water level
- pore water pressure
- water level observations during drilling and sampling
- water levels within and close to area of investigation

Requirements will include high, low or average level or pressure; accuracy; and the time period of observation. Recommendations will be given to certain methods in specific cases, such as piezocone dissipation tests in frictional materials, closed or open system etc.

8.1 Hydraulic conductivity

Requirements will be specified for hydraulic conductivity; storativity; hydraulic conductivity anisotropy ratio; and capillarity.

8.2 Thermal properties

Requirements will be specified for thermal conductivity (i.e. the ability of a material to transport thermal energy); thermal diffusivity (the ability of a material to equalize temperature differences); and thermal capacity (the ability of a material to store thermal energy).

9 REPORTING

The results of a geotechnical investigation shall be compiled in a Ground Investigation Report, which shall be referenced in the Geotechnical Design Report.