Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-366

EUROCODE 7 – Second generation - Interplay with Eurocode 8: Implications for ground investigation

EUROCODE 7 – Deuxième génération - Interaction avec l'Eurocode 8 Implications pour les investigations de terrain

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ABSTRACT: In the CEN/TC250 Programming Mandate M/515, the lack of compatibility between Eurocode 7 and Eurocode 8 was clearly addressed when directions for development of the new generation of EN 1997 and EN 1998 were outlined. In the present paper the most relevant modifications of the new Codes are illustrated outlining the inputs required by Eurocode 8, parts 1 and 5, for site categorisation and seismic geotechnical design, followed by the illustration of the new items introduced in Eurocode 7 to ensure that ground investigation and the resulting ground model properly consider seismicity between their objectives.

RÉSUMÉ: Dans le mandat de programmation M/515 du CEN/TC250, le manque de compatibilité entre l'Eurocode 7 et l'Eurocode 8 a été clairement abordé lorsque les orientations pour le développement de la nouvelle génération des EN 1997 et EN 1998 ont été définies. Dans le document, les modifications les plus pertinentes des nouveaux codes sont illustrées en présentant d'abord les entrées requises par l'Eurocode 8, parties 1 et 5, pour la catégorisation des sites et la conception géotechnique sismique, puis par l'examen des nouveaux éléments introduits dans l'Eurocode 7 pour garantir que l'investigation du sol et le modèle de sol qui en résulte prennent correctement en compte la sismicité entre leurs objectifs respectifs.

Keywords: Ground model; seismic geotechnical design; Eurocode 7; Eurocode 8; ground investigation.

1 INTRODUCTION

In the CEN/TC250 Programming Mandate M/515, the lack of compatibility between Eurocode 7 (EN 1997-1: 2004) and Eurocode 8 (EN 1998-5: 2004) was specifically addressed when directives for development of the new generation of EN 1997 and EN 1998 were given. To fulfil the Mandate, an Evolution Group 6 (EG6) was established by SC7 from which the following principles and line of actions were suggested: a) the design of a geotechnical structure is a unique process that needs to be accomplished by considering all possible boundary (e.g., loading) and environmental (e.g., seismicity) conditions since the very beginning of the design process; b) recommended design procedures must ensure a smooth transition between static and seismic design: transfer of seismic action effects to the ground should consider the possibility of permanent displacements of foundations and retaining structures and energy dissipation mechanisms in the ground; c) more emphasis is needed in both EN 1997 and EN 1998 for the assessment of seismic-dynamic properties of the ground: ground investigation covered in EN 1997-2 must include appropriate tests for seismic design (e.g.: geophysical methods for site investigation, cyclic and dynamic laboratory testing); d) verification of the seismic performance of a geotechnical structure should be possible with both approaches adopted in EN 1997, that is, Material factor approach (MFA) and Resistance factor approach (RFA).

Limiting to some relevant aspects only, the purpose of the paper is to illustrate and discuss from the specific perspective of Eurocode 7 how the Mandate requirements have been implemented and the practical consequences for geotechnical design within the new generation of Eurocodes.

2 THE CONTRIBUTE OF EUROCODE 7 TO SEISMIC DESIGN

Reading through Part 1 and Part 5 of FprEN 1998, it is clear that prEN1997-2023, hereafter indicated as EN 1997 for simplicity, has been conceived considering also the geotechnical inputs for seismic design. Most relevant information is in fact included among the objectives of the Ground Model, that is a tool conceived to represent all basic properties of a site, specifically those not dependent from the programmed construction. The content of the Ground Model includes, but is not limited to, the following items:

- Bedrock & structural geology
- Geology & geomorphology
- Seismicity
- Hydrogeological conditions
- Geotechnical conditions

The Ground Model should be developed from the very beginning of design and progressively developed and updated with information from ground investigation (desk studies; field and laboratory investigations; information obtained with monitoring).

In FprEN 1998-1-1:2024, hereafter indicated simply as EN 1998-1, site conditions must be assessed before any quantitative evaluation of the seismic action expected at the site. With this aim, knowledge of the site geology and seismicity from regional seismic risk maps is needed; potentially active faults or other causes of permanent ground deformation and settlements, such as the presence of unstable slopes affecting the area or of potentially liquefiable soil deposits under the considered seismic action, should be identified. According to the above list, all these items are in fact the specific ingredients of the Ground Model to be progressively addressed from the beginning of the design process (JRC 2024).

In EN 1998-1, site conditions are discussed in Clause 5 for the evaluation of the seismic action. In this clause a site categorisation is proposed for simplified assessment of stratigraphic amplification. Categories are preferentially established on the basis of the profile of the shear wave velocity v_s in the ground and of the depth of the conventional seismic bedrock H_{800} (i.e., the depth at which v_s is larger than 800 m/s). According to EN 1998-1, the site may fall in one of six different categories, ranging between A and F, as described in Table 1, where $v_{s,H}$ is the equivalent shear wave velocity computed over the depth H_{800}.

Table 1. Site categorisation based on bedrock depth H_{800} and the equivalent shear wave velocity value $v_{s,H}$. (reproduced from FprEN 1998-1-1:2024).

	Ground class	**Stiff**	**Medium stiffness**	**Soft**
Depth class	$v_{s,H}$ range / H_{800} range	400 m/s ≤ $v_{s,H}$ < 800 m/s	250 m/s ≤ $v_{s,H}$ < 400 m/s	150 m/s ≤ $v_{s,H}$ < 250 m/s
very shallow	H_{800} ≤ 5m	A	A	E
shallow	5m < H_{800} ≤ 30m	B	E	E
intermediate	30m < H_{800} ≤ 100m	B	C	D
deep	H_{800} ≥ 100m	B	F	F

When the full set of information is not available, the normative Annex B of EN 1998-1 gives a simplified procedure to assign the site category. Such procedure relies upon a combination of qualitative and quantitative parameters, the former describing the predominant soil type and the latter its consistency, through an estimate of its stiffness range. Two more options are given by EN 1998-1 when information for site classification is incomplete: when direct measurements of v_s are not available, it is possible to estimate the v_s profile from well-established empirical correlations between v_s and geotechnical parameters or field test results; when the bedrock depth H_{800} is not known the soil category may be assigned from the equivalent value of the shear wave velocity $v_{s,H}$ and the fundamental frequency of the soil deposit f_0. Finally, the identification of the bedrock may also be obtained from geological, geophysical, or geotechnical information, including microzonation maps. Whatever the procedure to characterise the ground is, standard or simplified, a field investigation is always needed to quantify ground properties. Such investigation shall include the identification of the soil constituting the deposit and some intrusive in situ testing (e.g. static or dynamic penetration tests, vane and pressuremeter tests or laboratory testing). With the 2nd generation of Eurocodes the geotechnical designer must keep well in mind that geotechnical seismic design needs to be supported with data collected with the ground investigation and that such data must be included in the Ground Model. This is not the case for the present version of Eurocodes, where the ground investigation for the seismic design is not explicitly included in the ground investigation for geotechnical design, resulting in a very weak link between EN 1998-5:2004 and EN 1997-2:2007 for the evaluation of ground properties.

A clear separation between the two Eurocodes can also be found in the approaches for verification of limit states. Significant steps have then been taken to implement compatibility between static and seismic geotechnical design. According to FprEN 1998-5:2024, hereafter shorted as EN 1998-5, both the Material Factor Approach (MFA) and the Resistance Factor Approach (RFA) may be used to verify that the design resistance R_d is greater or equal to the design value of the effects of actions E_d. This is not the case for the present version of EN 1998-5, that allows only verifications with MFA. Moreover, a very close link between EN 1998-5 and EN 1997-2 (2nd generation) emerges from Clause 6 of the seismic Code on ground properties. According to 6.1(2), derived and representative ground properties are explicitly considered for seismic design and their values are those indicated by the Ground Model and the Geotechnical design model respectively. Note that in the present version of EN 1998-5, a distinction between derived and characteristic values of ground properties was not considered, and design values did not appear explicitly in the code. On the contrary, with the 2nd generation of EN 1998-5, many requirements on the ground investigation are given. Among these: suggestion for measurement of the v_s profile with geophysical methods or alternatively the use of empirical correlations with standard penetration and/or static cone penetration tests. Finally, specific reference to cyclic and dynamic laboratory tests is made for a direct derivation of geotechnical properties, such as strain dependent stiffness and damping ratio. In turn, many clauses of its parts 1 and 2 provide indications on how implement the Ground model considering specific inputs for seismic design.

Criteria to design the ground investigation are given in EN 1997-2. In the preliminary investigation seismic hazard has to be addressed and determined. Moreover, within the scopes of the design investigation, seismic properties of ground are explicitly indicated in Clause 3. Criteria given for the planning of investigations in Clause 5.4.1 (4) prescribe that the extent of investigation shall cover the depth for calculation of the seismic ground response as specified in EN 1998-1 Clause 5 and EN 1998-5 Clause 6. A note to the same clause states that the Zone of Influence under cyclic, dynamic and seismic actions can be different from the one under static loading; consequently, the extent and the objectives of ground investigations must be revised accordingly. Although never actually stated in the Code, the above criteria must be reflected by the Ground Model whose extent should match the Zone of Influence that has been identified for the project and that must fully cover the volume of investigation.

The determination of ground properties for cyclic, dynamic and seismic design is addressed by EN 1997-2 Clause 10. Ground investigations should provide relevant information on:

- stress-strain response to cyclic actions, including small strain stiffness,
- energy dissipation properties,
- development of excess pore water pressures under cyclic actions,
- shear strength under cyclic action,
- post cyclic behaviour in terms of post-cyclic shear strength,
- dissipation of cyclic-induced pore water pressure, and other associated deformations,
- cyclic undrained shear strength for liquefaction assessment (see EN 1998-5).

The direct determination of the shear and compressional wave velocities is addressed by Table 10.2 of EN 1997-2 with a comprehensive list of geophysical tests followed by recommendations on their selection. Consistently with the cases considered by EN 1998-1 a list of tests to be used for indirect determination of the shear wave velocity profile is also given, with indication of the appropriate test standard to follow and of the requirements for interpretation of results. Particularly relevant to implement the seismic site categorisation of EN 1998-1 is the subclause 10.7, addressing the determination of the position of the bedrock and of the fundamental frequency f_0 of the soil deposits. Depth of the seismic bedrock may be obtained from geophysical tests or by indirect methods if accompanied by direct inspection of samples retrieved from the bedrock layer. The fundamental frequency of soil deposits may be estimated from records of ambient vibrations at the ground surface transformed in the horizontal-to-vertical spectral ratio (HVSR). Laboratory tests for measuring response to cyclic and dynamic actions are listed in Table 10.1 of Clause 10, reproduced below as Table 2, with indications of the strain level for which each testing method is appropriate. A specific subclause considers laboratory testing to obtain information on the variation of the secant shear modulus and damping ratio against shear strain. These data are particularly relevant for numerical modelling of geotechnical structures subjected to seismic loading. When results from laboratory testing are not available, EN 1997-2 presents in Annex G methods to obtain seismic properties indirectly from empirical correlations with soil physical properties or with results of field testing.

Table 2. Laboratory tests for measuring response to cyclic and dynamic actions. (reproduced from prEN 1997-2).

	Laboratory test (and associated test standards)					
Test	**Cyclic torsional shear**	**Cyclic direct simple shear**	**Cyclic triaxial**	**Resonant column**	**Bender elements**	**Cyclic triaxial for rock**
Standard	See Table B.8					
Strain level						
Very small ($< 10^{-5}$)	(full)	-	-	full	one	(full)
Small (10^{-5} -10^{-2})	full	full	(full)	(full)	-	full
Medium (10^{-2} -10^{-1})	-	(full)	full	-	-	-

- = not applicable; 'one' = one conventional value; 'full' = full curve; () = partially applicable

3 CONCLUSIVE REMARKS

The 2nd generation of Eurocode 7 has been conceived with the formalization of a new concept, that is the Ground Model defined as a site-specific collection of data about geometry and properties of the ground and groundwater, based on results from field investigation and other available data. This definition implies that also the seismic properties of the ground must be included in the Ground Model, and this has important consequences on the design of Ground Investigation and on Reporting. EN 1998-Parts 1 and 5 and EN 1997 Parts 1 and 2 have been considerably influenced by the assumptions that the Ground Investigation is a comprehensive activity, programmed to fulfil all the needs for geotechnical design including those motivated by seismic actions. The Ground Model is the tool to share among all the actors involved in design a comprehensive representation of the site. It contains all the features to ensure safety and serviceability for any possible design situations, including the seismic one. A specific Guideline on the implementation of the Ground Model will be made available by TC250/SC7, together with similar guidelines on the most innovative aspects of the 2nd generation of Eurocode 7.

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