General overview of EN 1998-5:2021
Basis of design
Seismic action for geotechnical structures and systems

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OUTLINE OF PRESENTATION

- Why revising EN 1998-5 ?
- Overview of content of EN 1998-5
- Basis of design with emphasis on particular aspects linked to EN 1998-5
- Methods of analyses
- Seismic action in EN 1998-5
- Soil properties

NEEDS AND REQUIREMENTS FOR REVISION

CEN Enquiry

- Reduce the conservatism of the force-based approaches
  - ❖Revisit the material factors
- Develop the approaches for piles, retaining structures
- Develop the section on Soil-Structure Interaction (SSI)

SC8

- Develop a section on the seismic actions on underground structures
- Introduce the displacement-based approaches as alternatives to force-based approaches

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EN 1998-5

- Part 5 is the chapter, among the 6 parts of the seismic Eurocode (EC8), related to Geotechnical issues.
- Part 5 is a transverse document that should cover
  - new and existing structures
  - Geotechnical systems and geotechnical structures
- Part 5 complements for the seismic design situations and is not a substitute to EN 1997

EN 1998-5 : Project Team

- Alain PECKER : Consultant & Ecole des Ponts ParisTech , Paris
- Luigi CALLISTO : Sapienza Università, Rome
- Antonio CORREIA : Laboratório Nacional de Engenharia Civil, Lisbon
- George GAZETAS : National Technical University, Athens
- Amir KAYNIA : Norwegian Geotechnical Institute, Oslo
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- Kyriazis PITILAKIS : Aristotle University, Thessaloniki
- Philippe BISCH : Chairman of SC8

TABLE OF CONTENT OF EN 1998-5

- ★ Chapter 4 : Basis of design
- ★ Chapter 5 : Seismic action
- Chapter 6 : Ground properties
- Chapter 7 : Requirements for siting and foundation soils
- ★ Chapter 8 : Soil structure interaction
- ★ Chapter 9 : Foundation systems
- ★ Chapter 10 : Earth retaining structures
- ★ Chapter 11 : Underground structures

★ (red) New
★ (yellow) Significantly expanded

EN 1998-5 : Annexes

- Annex A: Reduction of the seismic action as an effect of wall height and predominant wavelength
- Annex B: Procedure for liquefaction analyses
- Annex C: Evaluation of soil settlements
- Annex D: Simplified evaluation of soil structure interaction effects
- Annex E: Impedance functions for surface and deep foundations
- Annex F: Seismic bearing capacity of shallow foundations
- Annex G: Evaluation of earth pressures on retaining structures
- Annex H: Simplified evaluation of peak ground parameters for seismic design of underground structures
- Annex I: Simplified analytical expressions for the seismic design of tunnels
- Annex J: Impedances functions for underground structures

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BASIS OF DESIGN

- Peculiar aspect : Part 5 has to deal with
  - Geotechnical structures
    - ➢ structure that includes ground or a structural member that relies on the ground for resistance; e.g. retaining walls , slope, dike.
  - Geotechnical systems
    - ➢ complex systems where one geotechnical structure interacts with other structures or geotechnical structures; e.g. retaining walls with a supported structure at the crest, slopes with a structure at the crest or toe.

IMPLICATIONS

GEOTECHNICAL STRUCTURES

- Performance requirements
  - Defined in EN 1998-5
- Consequence classes / Return Period
  - Three classes CC1, CC2 and CC3 (NDP)

Limit State	Consequence class		
	CC1	CC2	CC3
NC	800	1600	2500
SD	250	475	800
DL	50	60	60

GEOTECHNICAL SYSTEMS

- Performance requirements
  - Defined in EN 1998-1-1 according to LS
- Consequences classes / Return Period
  - Those of the structure

SEISMIC ACTION CLASSES

- Defined in EN 1998-1-1

$$S_\delta = \delta F_\alpha F_T S_{\alpha,475}$$

- Used to classify the seismic action

Seismic action class	Range of seismic action index
Very low	$S_\delta < 1{,}30\ m/s^2$
Low	$1{,}30\ m/s^2 \leq S_\delta < 3{,}25\ m/s^2$
Moderate	$3{,}25\ m/s^2 \leq S_\delta < 6{,}50\ m/s^2$
High	$S_\delta \geq 6{,}50\ m/s^2$

- Methods of analyses and performance requirements in EN 1998-5 depend on seismic action index S_δ

SEISMIC ACTION INDEX

$$S_{\delta} = \delta F_{\alpha} F_{T} S_{\alpha,475}$$

- δ : NDP

GEOTECHNICAL STRUTURES

	Consequence class		
	CC1	CC2	CC3
δ	0,6	1,0	1,5

GEOTECHNICAL SYSTEMS

- Values of δ are equal to those of the structure (see relevant parts of EC8)

METHODS OF ANALYSES

- Force-based approach (FBA)
  - Compliance checked in terms of generalised stresses
- Displacement-based approach (DBA)
  - Compliance checked by comparison of permanent displacements to acceptable ones

$$E_{\mathrm{Fd}} \leq R_{\mathrm{d}}$$

Design value of action
- FBA: generalised stresses
- DBA: calculated displacements

Design value of
- FBA: resistance
- DBA: allowable displacements

DESIGN VALUE OF RESISTANCE R_d

- Material factor approach (MFA): preferred choice in EN 1998-5
  - Allowed for displacement-based or force-based approaches

$$R_d = R\left\{\frac{X_k}{\gamma_m}; a_d; \sum F_{Ed}\right\}$$

- Resistance factor approach (RFA)
  - Allowed only for force-based approaches

$$R_d = \frac{1}{\gamma_R} R\left\{X_k; a_d; \sum F_{Ed}\right\}$$

- Effect Factor Approach (EN 1997)
  - Does not apply to seismic design situation

DISPLACEMENT-BASED APPROACH

- Acceptable methods to calculate the induced permanent displacements include:
  - Non-linear static analyses
  - Response history analyses
- Response history analyses require the use of accelerograms obtained from natural records (selected as per EN 1998-1-1:2021, 5.2.3.1) or site-specific response analyses
- Although EN 1998-1-1 allows artificial or spectrally matched accelerograms, determination of ground permanent deformations or displacements are better estimated with natural accelerograms recorded in real earthquakes

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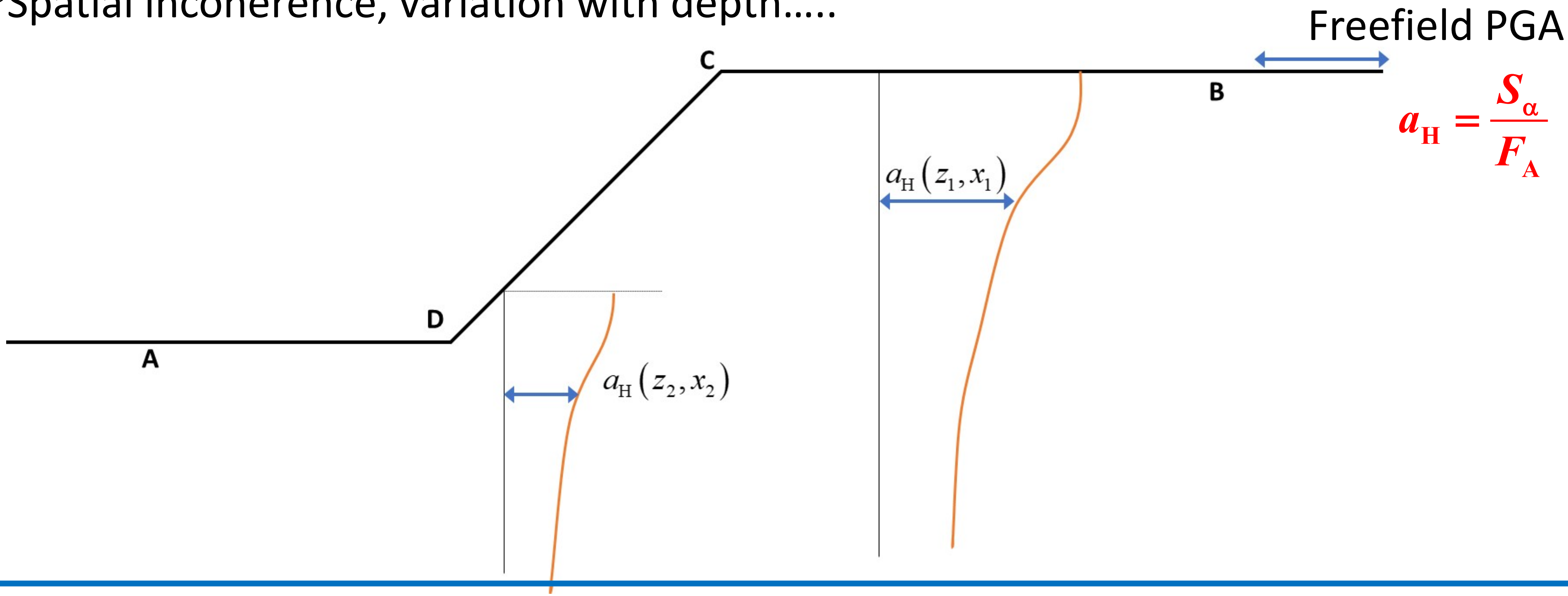
SEISMIC ACTION

- Stability of geotechnical structures/systems involves large volume of soils. Seismic action is not uniform throughout the volume
  - ➢Spatial incoherence, variation with depth…..



SEISMIC ACTION

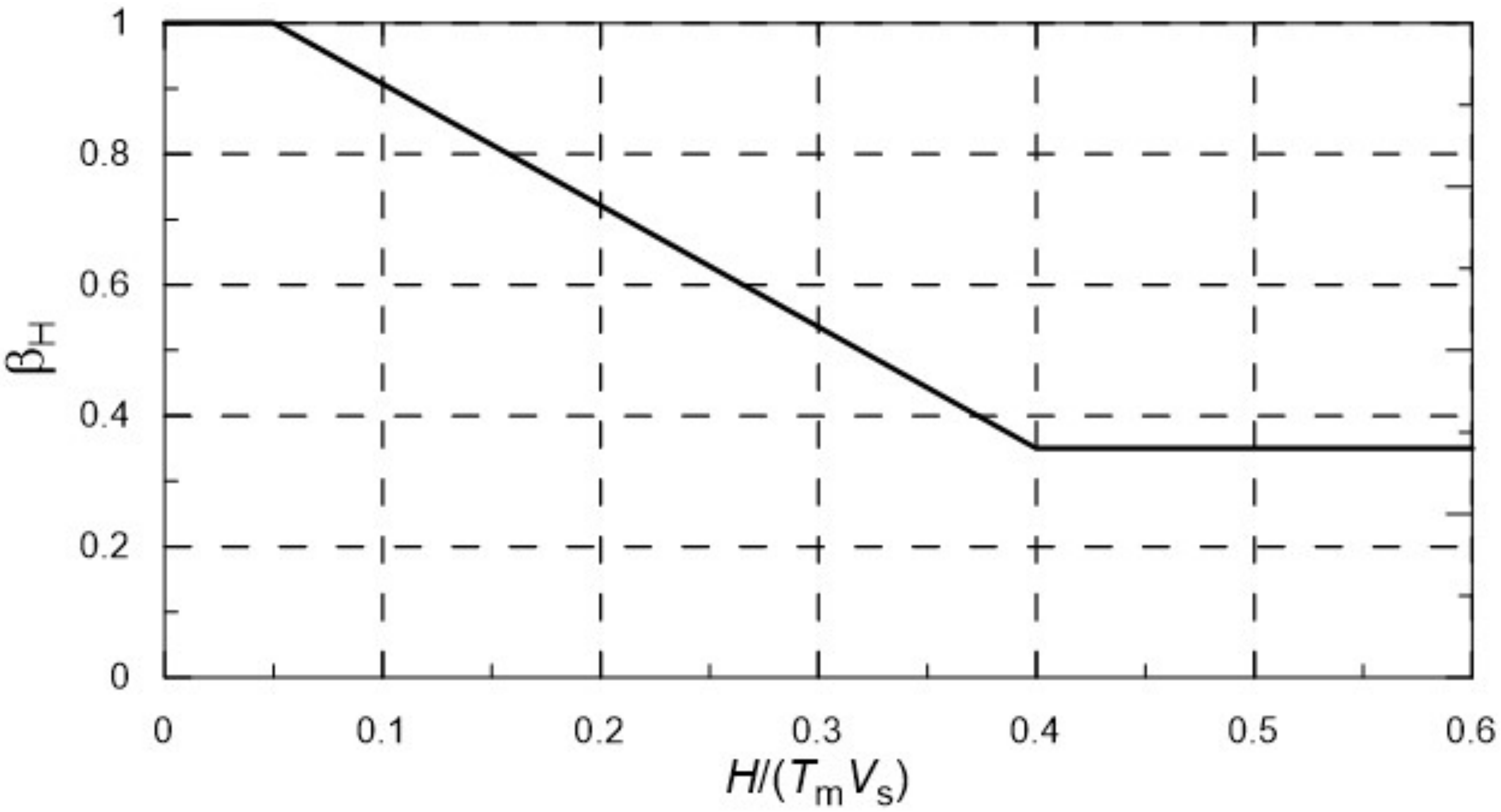
- Seismic action defined by a conventional horizontal ground acceleration a_H

$$a_H = \frac{\beta_H}{\chi_H}\frac{S_\alpha}{F_A} = \frac{\beta_H}{\chi_H} PGA_e$$

- PGA_e : design value of horizontal peak ground acceleration
- β_H : coefficient reflecting the spatial variation with depth of the horizontal ground motion within the ground mass ($0 \leq \beta_H \leq 1$)
- Horizontal spatial variability of ground motion defined in EN 1998-1-1: 5.2.3.2

SEISMIC ACTION : VARIABILITY WITH DEPTH

- Applicable to FBA or DBA
- Depends on model and method of analysis
- Can be computed from site response analysis
- Simplified evaluation is provided in Annex A



H slope height or height of retaining structure in contact with the soil

V_S shear wave velocity

$T_m = (T_B + T_C)$

SEISMIC ACTION

$$a_H = \frac{\beta_H}{\chi_H} \frac{S_\alpha}{F_A} = \frac{\beta_H}{\chi_H} PGA_e$$

- χ_H : coefficient reflecting the amplitude of accepted permanent displacements of the soil-structure system induced by the horizontal ground motion for the considered consequence class and limit state
- χ_H : reflects the nonlinear soil behaviour; it depends on soil type and structure
- In DBA χ_H shall be taken equal to 1,0.

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GROUND PROPERTIES : Deformation

- The profile of the shear wave velocity *Vs* in the ground should be regarded as the most reliable indicator of the stiffness of the ground layers for seismic design.
- Direct measurement of the *Vs* profile should be used for moderate and high seismic action classes
- For all other cases, the *Vs* profile may be estimated by empirical correlations with in-situ tests

Seismicity level	$150 \leq v_s < 250$ m/s		$250 \leq v_s < 400$ m/s		$400 \leq v_s < 800$ m/s		800 m/s $\leq v_s$	
	G/G_0	ξ	G/G_0	ξ	G/G_0	ξ	G/G_0	ξ
Very low	0,70 (±0,08)	0,04	0,80 (±0,09)	0,03	1,00	0,03	1,00	0,02
Low	0,50 (±0,14)	0,07	0,65 (±0,16)	0,05	0,80 (±0,10)	0,03	1,00	0,02
Moderate	0,30 (±0,10)	0,10	0,50 (±0,20)	0,07	0,70 (±0,10)	0,05	1,00	0,02
High	0,20 (±0,10)	0,20	0,40 (±0,20)	0,12	0,60 (±0,20)	0,10	0,90 (±0,10)	0,02

NOTE 1 The seismicity level is defined in Table 5.2 of prEN 1998-1-1:2021.

NOTE 2 G_0 is the best estimate value at small strains ($< 10^{-5}$), see also prEN 1997-2:2021, 9.1.4 and Annex F.

GROUND PROPERTIES : Strength

- Saturated soils should be considered to behave under undrained conditions
- Soil undrained behaviour may be studied in terms of total stresses, or in terms of effective stresses with due account of the pore water pressure
- In terms of total stresses
  - For fine-grained soils, the appropriate strength parameter should be the undrained shear strength c_u ; c_u should consider cyclic degradation effects under long duration earthquake actions.
  - For coarse-grained soil, the appropriate strength parameter should be the cyclic undrained shear strength $\tau_{cy,u}$

GROUND PROPERTIES : Partial factors

- In MFA approach partial factors γ_M should be applied to the ground strength parameters
- In RFA approach partial factors γ_R should be applied to the resistance
- Partial factors are NDP
- Important remark: values of χ_H given in EN 1998-5 have been calibrated for the recommended partial factors
  - If different values for γ_M are specified in National Annexes, χ_H needs to be recalibrated

RECOMMENDED PARTIAL FACTORS (NDP)

EN 1998-5:2021

- Undrained shear strength c_u : 1,0
- Drained cohesion c' : 1,0
- Drained friction angle ($\tan\phi'$) : 1,0
- UC strength (rock): 1,0
- Undrained cyclic shear strength: 1,25
- Interface friction angle ($\tan\delta_f$) : 1,0
- Global resistance factor (RFA) : 1,0

EN 1998-5:2004

- Undrained shear strength c_u : 1,4
- Drained cohesion c' : N/A
- Drained friction angle ($\tan\phi'$) : 1,25
- UC strength (rock): 1,4
- Undrained cyclic shear strength: 1,25
- Interface friction angle ($\tan\delta_f$) : N/A
- Global resistance factor (RFA) : N/A

THANK YOU FOR YOUR ATTENTION