EU-Russia Regulatory Dialogue: Construction Sector Subgroup

Seminar ' Bridge Design with Eurocodes'

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DG Joint Research Centre
DG Enterprise and Industry

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Federal Highway Agency, Ministry of Transport

European Committee for Standardization
TC250 Structural Eurocodes

Design of foundations for bridges : Eurocode 7 on 'Geotechnical design'

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Former chairman of Eurocode 7 (1998-2004)

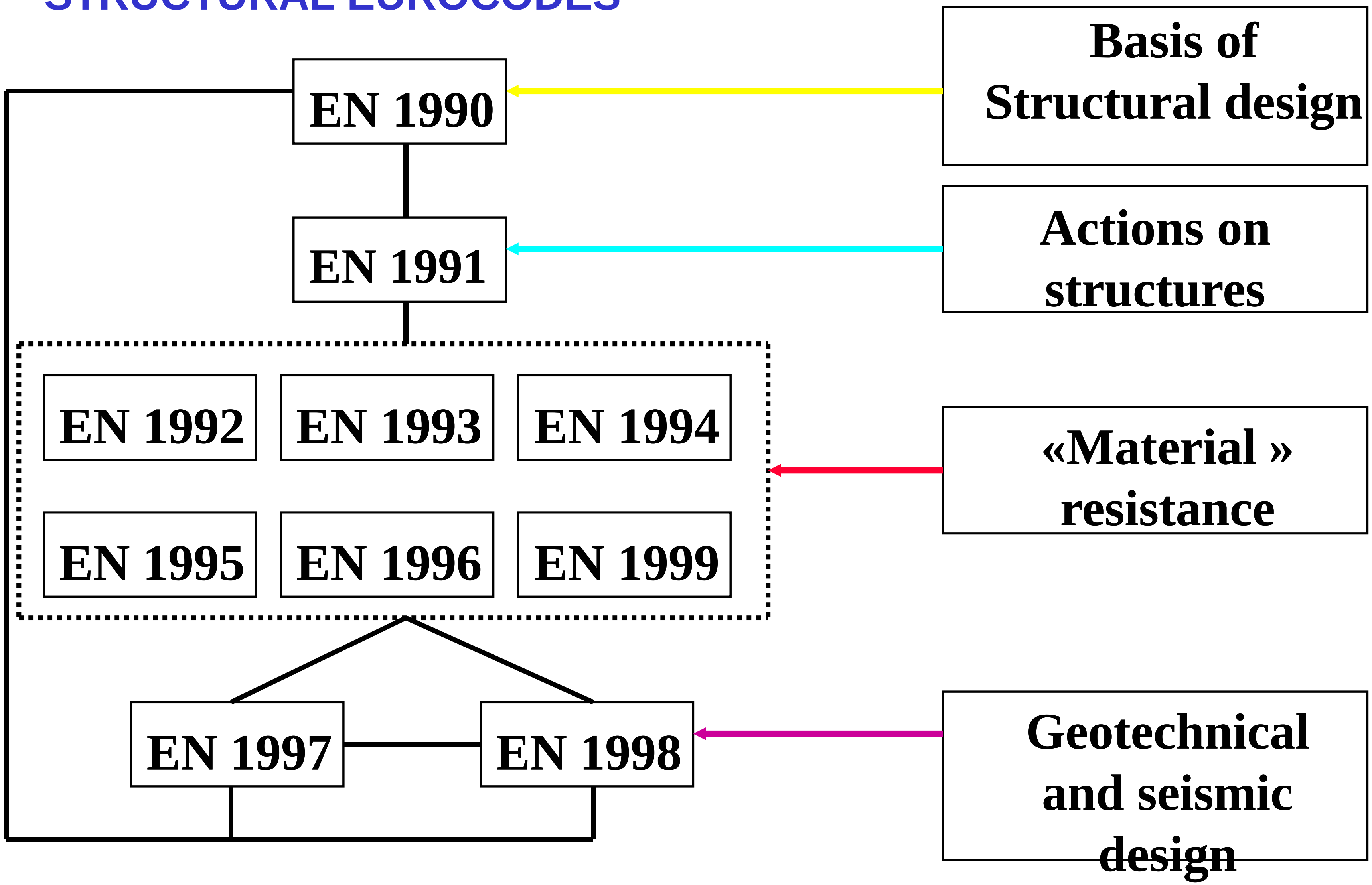
Agenda

1. General presentation of Eurocode 7 'Geotechnical design'
   - Contents of Part 1 and 2
   - Specific aspects of EN 1997-1:
   - 3 ULS-Design Approaches (DAs)
   - SLS and allowable movements of foundations
   - Shallow foundations
   - (not treated today:
   - Deep foundations
   - Retaining structures)

2. Application to bridge design
   - Geotechnical data
   - Squat pier P1
     - ULS-bearing capacity
     - SLS-settlement

General presentation of Eurocode 7

STRUCTURAL EUROCODES



Eurocode 7 – Geotechnical design

for buildings and bridges

EN 1997-1 (2004) : Part 1 - General rules

EN 1997-2 (2007) : Part 2 - Ground investigation and testing

Contents of Part 1 (EN 1997-1)

Section 1 General
Section 2 Basis of geot design
Section 3 Geotechnical data
Section 4 Supervision of construction, monitoring and maintenance
Section 5 Fill, dewatering, ground improv and reinfor
Section 6 Spread foundations *
Section 7 Pile foundations
Section 8 Anchorages
Section 9 Retaining structures
Section 10 Hydraulic failure
Section 11 Site stability
Section 12 Embankments

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1997-1

November 2004

ICS 91.120.20

Supersedes ENV 1997-1:1994

English version

Eurocode 7: Geotechnical design - Part 1: General rules

Eurocode 7: Calcul géotechnique - Partie 1: Règles générales

Eurocode 7: Entwurf, Berechnung und Bemessung in der Geotechnik - Teil 1: Allgemeine Regeln

This European Standard was approved by CEN on 23 April 2004.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

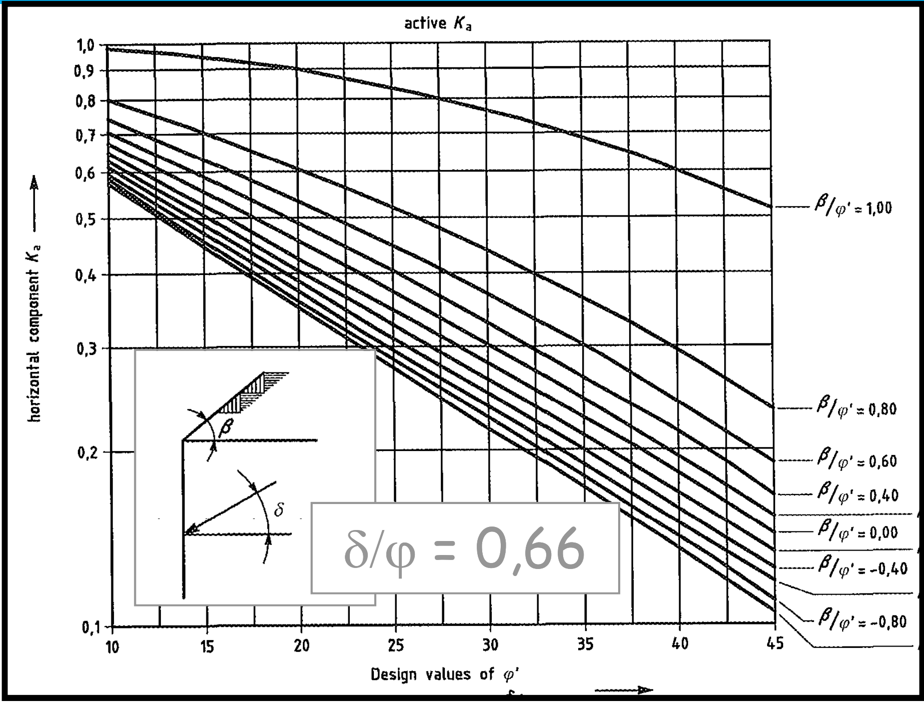
EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

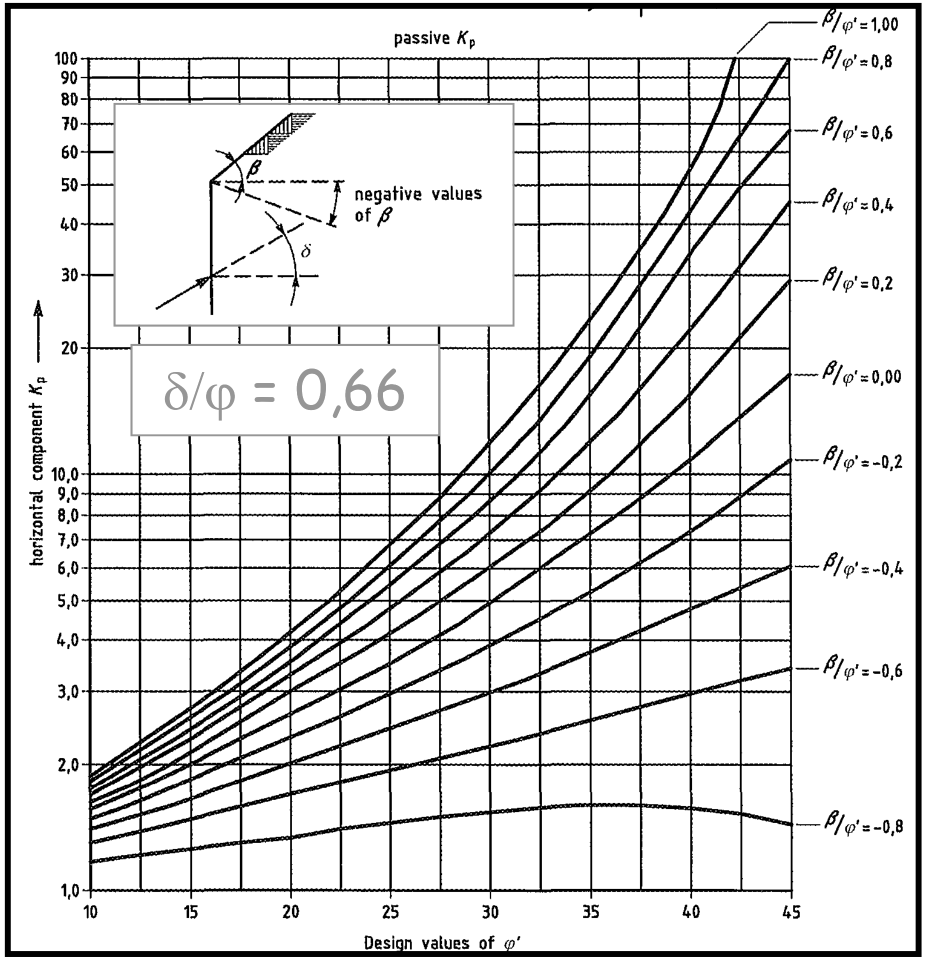
Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 1997-1:2004: E

\> + number of Informative annexes with calculation methods

Active /Passive earth pressures - annex C (Informative)





Active/Passive earth pressures

β = - φ à + φ

δ = 0 ; 2/3φ and φ

"c-φ" model (Annex D)

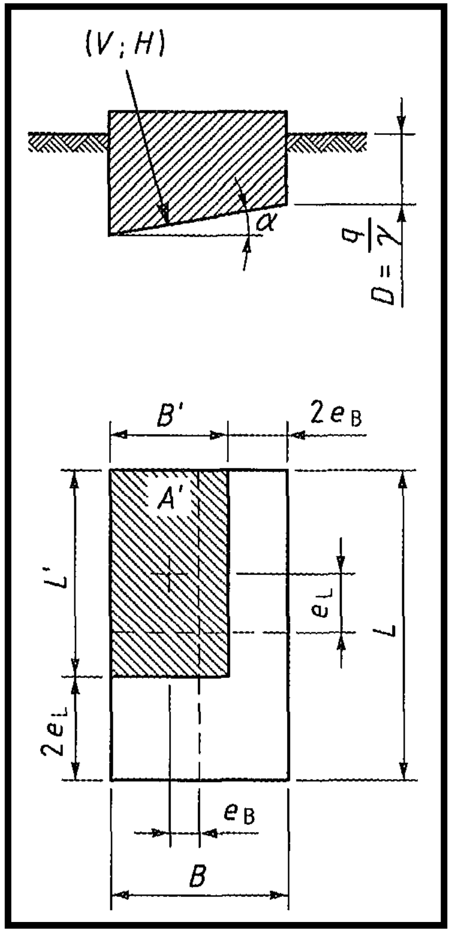
$$R/A' = c' \times N_c \times b_c \times s_c \times i_c$$
$$+ q' \times N_q \times b_q \times s_q \times i_q$$
$$+ 0{,}5 \times \gamma' \times B' \times N_\gamma \times b_\gamma \times s_\gamma \times i_\gamma$$

Pressuremeter model *(annexe E)*

$$R/A' = \sigma_{v0} + k \times p^*_{le}$$

Settlement of foundations (Annex F)

Adjusted elasticity: $s = p \times b \times f / E_m$



Contents of Part 2 (EN 1997-2)

Section 1 General

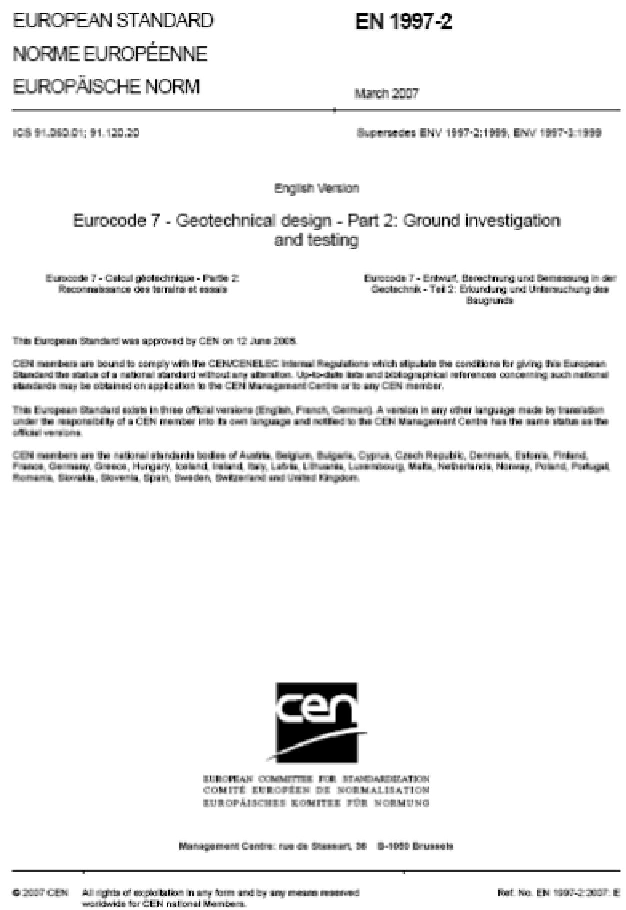
Section 2 Planning and reporting of ground investigations

Section 3 Drilling, sampling and gw measurements

Section 4 Field tests in soils and rocks

Section 5 Laboratory tests on soils and rocks

Section 6 Ground investigation report


EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1997-2

March 2007

ICS 91.060.01; 91.120.20

Supersedes ENV 1997-2:1999, ENV 1997-3:1999

English Version

Eurocode 7 - Geotechnical design - Part 2: Ground investigation and testing

Eurocode 7 - Calcul géotechnique - Partie 2: Reconnaissance des terrains et essais

Eurocode 7 - Entwurf, Berechnung und Bemessung in der Geotechnik - Teil 2: Erkundung und Untersuchung des Baugrunds

This European Standard was approved by CEN on 12 June 2006.

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Ref. No. EN 1997-2:2007: E

> Also a number of Informative annexes

Specific aspects of Eurocode 7-1

Characteristic values and design values

ULS Design Approaches

SLS and deformations of structures

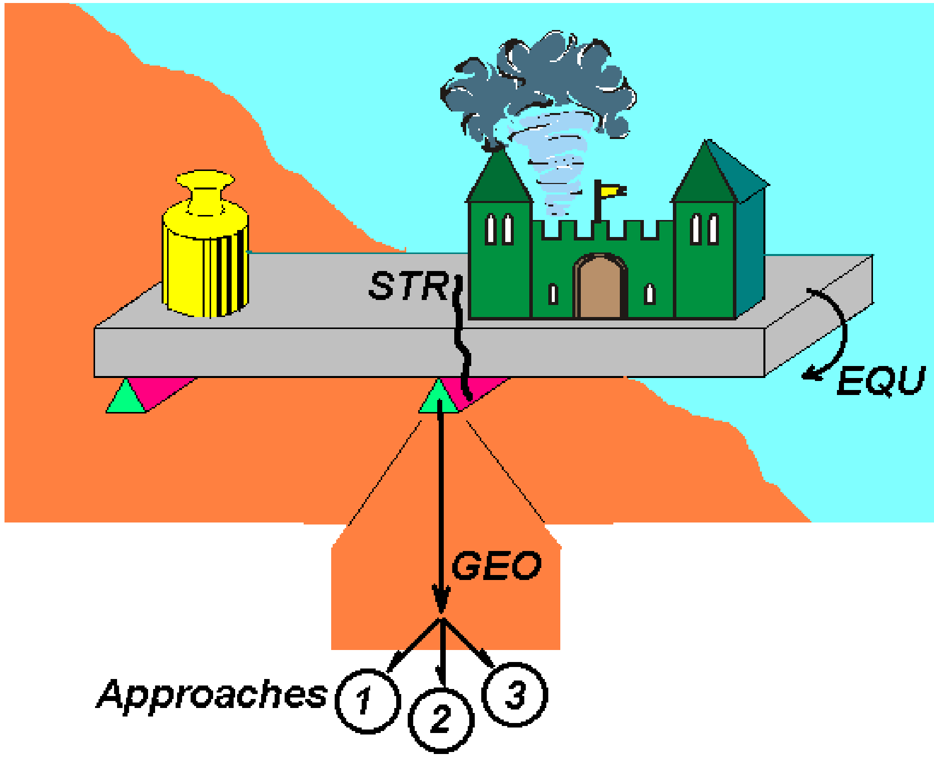
P The characteristic value of a geotechnical parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state.

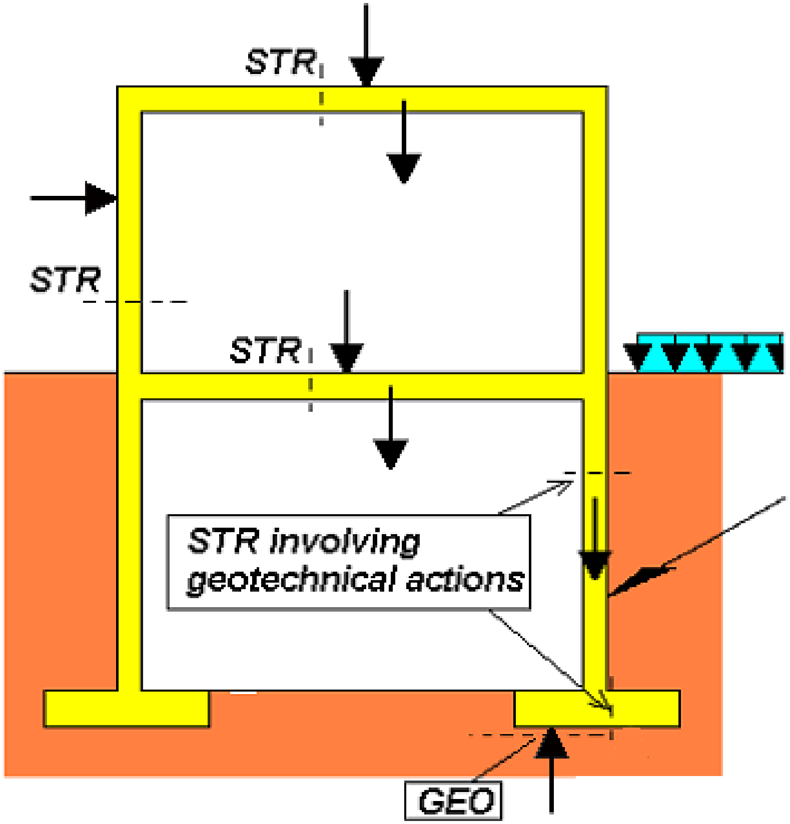
If statistical methods are used, the characteristic value should be derived such that the calculated probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5%.

Ultimate limit states – Eurocode 7-1

- EQU : loss of equilibrium of the structure
- STR : internal failure or excessive deformation of the structure or structural elements
- GEO : failure or excessive deformation of the ground
- UPL : loss of equilibrium due to uplift by water pressure (buoyancy) or other vertical actions
- HYD : hydraulic heave, internal erosion and piping caused by hydraulic gradients

EN1990 - Ultimate limit states EQU and STR/GEO





$E_d < R_d$

J.A Calgaro

Design values of geotechnical parameters

Design value of a parameter : $X_d = X_k / \gamma_M$

Design values of actions and resistances

fulfilling for STR/GEO ULS : $E_d \leq R_d$

$E_d = E\{\gamma_F.F_k ; X_k / \gamma_M\}$ and $R_d = R\{\gamma_F.F_k ; X_k / \gamma_M\}$

(= "at the source")

or $E_d = \gamma_E.E\{F_k ; X_k\}$ and $R_d = R\{F_k ; X_k\} / \gamma_R$

Serviceability limit states SLS

European Commission

Verifications :

$$E_d \leq C_d$$

C_d = limiting design value of the relevant serviceability criterion (eg settlements, relative rotations, etc.)

E_d = design value of the effects of actions specified in the serviceability criterion, determined on the basis of the relevant combination

all γ_F and $\gamma_M = 1.0$

Shallow foundations
STR/GEO Ultimate limit states (ULS)

Bearing resistance:

$$V_d \leq R_d = R_k \ / \gamma_{R;v}$$

(R_k : analytical – Annex D, semi-empirical – Annex E or prescriptive - Annex G)

Sliding resistance :

$$H_d \leq R_d + R_{p;d}$$

$$[+ R_d \leq 0{,}4 \ V_d \ ]$$

- drained conditions :

$R_d = V'_d \tan \delta_d$ <u>or</u> $R_d = (V'_d \tan \delta_k) / \gamma_{R;h}$

- undrained conditions

$R_d = A' c_{u;d}$ <u>or</u> $R_d = (A' c_{u;k}) / \gamma_{R;h}$

Overall stability

Large eccentricities : special precautions if :

$e/B > 1/3$ (or $0{,}6\ \phi$)

Structural failure due to foundation movement

Structural design of spread foundation:
see EN 1992

STR/GEO persistent and transient design situations (spread foundations without geotechnical actions)

Design approach	Actions on/from the structure γ_F	Geotechnical resistance γ_R or γ_M (at the source)
1	1,35 and 1,5	$\gamma_{R;v} = 1,0$ $\gamma_{R;h} = 1,0$
	1,0 and 1,3	$\gamma_M = 1,25$ (on c' and tanφ') or $\gamma_M = 1,4$ (on c_u)
2	1,35 and 1,5	$\gamma_{R;v} = 1,4$ $\gamma_{R:h} = 1,1$
3	1,35 and 1,5	$\gamma_M = 1,25$ (on c' and tanφ') or $\gamma_M = 1,4$ (on c_u)

Serviceability limit states (SLS)

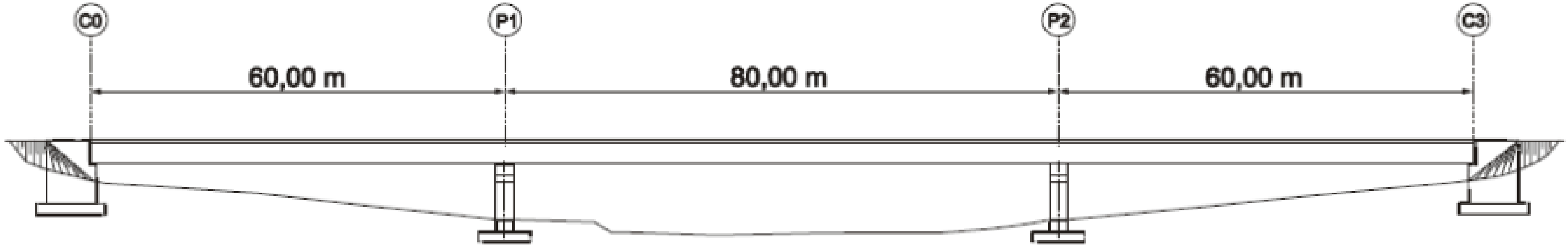
Include both immediate and delayed settlements

Assess differential settlements and relative rotations

Check that limit values for the structure are not reached

frequent questions to structural engineers : what are they?...

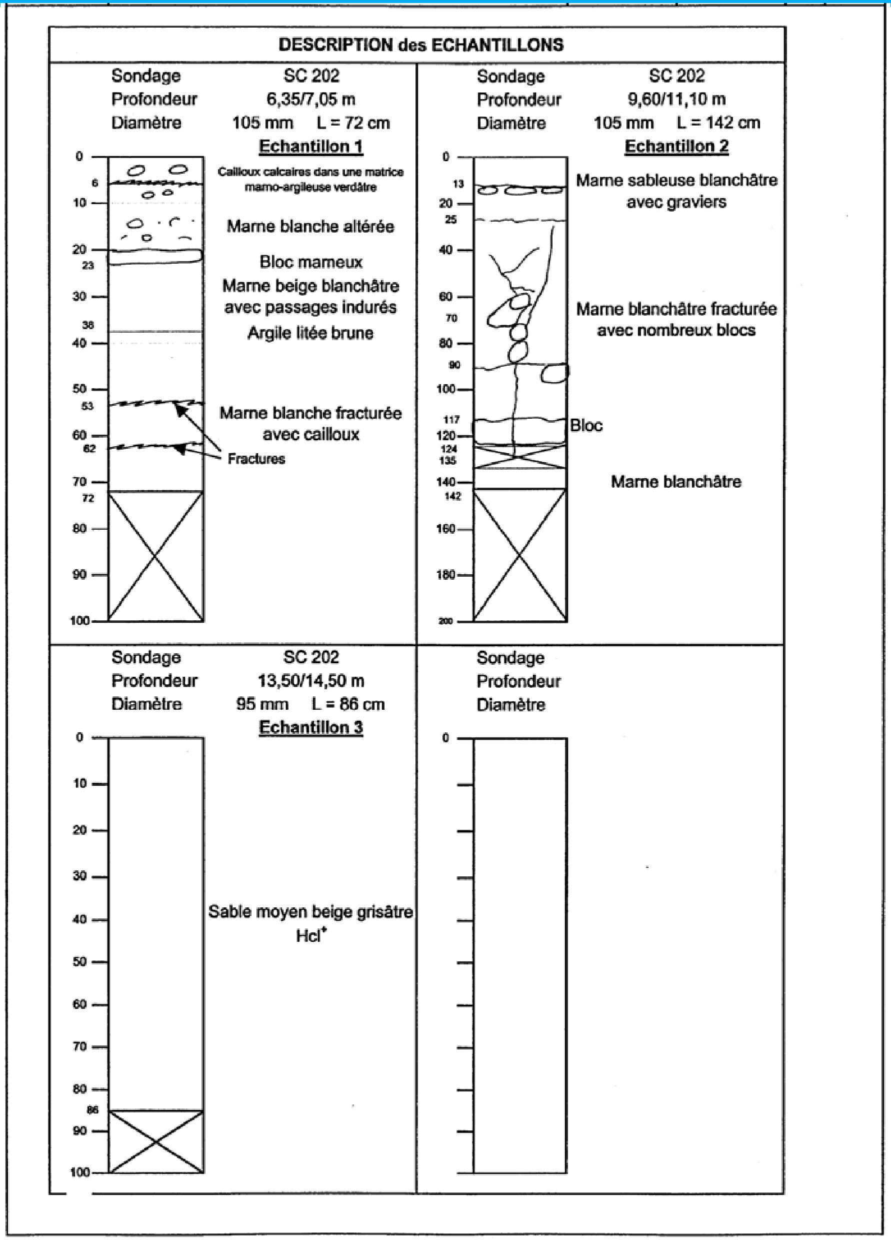
Bridge design



http://eurocodes.jrc.ec.europa.eu/doc/1110_WS_EC2
/report/Bridge_Design-Eurocodes-Worked_examples.pdf

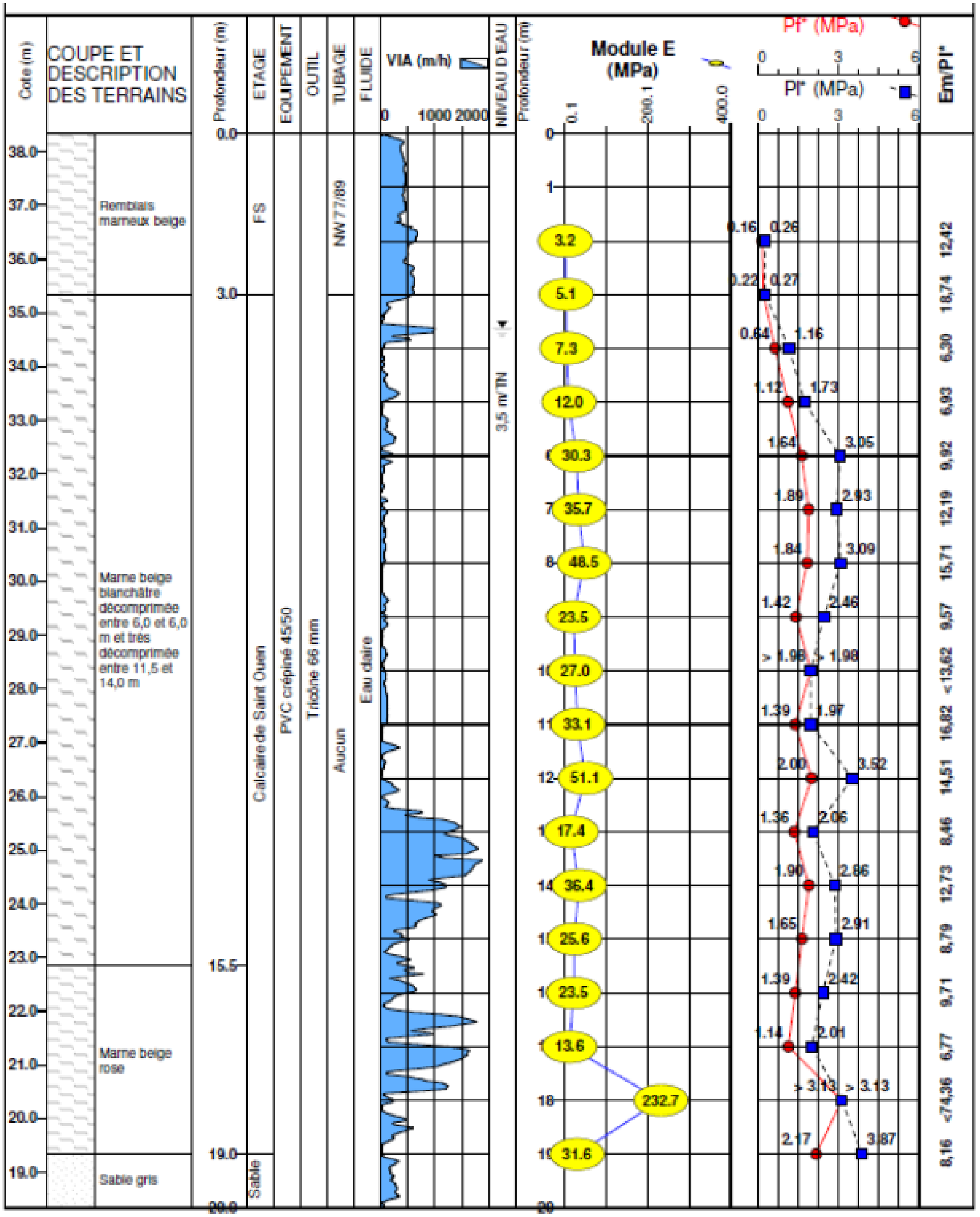
European Commission

Geotechnical data



Identification of soils : core sampling results between abutment C0 and pier P1

Geotechnical data



Results of pressuremeter tests between abutment C0 and pier P1

Normally fractured calcareous marl (at 2,5 m depth and 3 m depth):

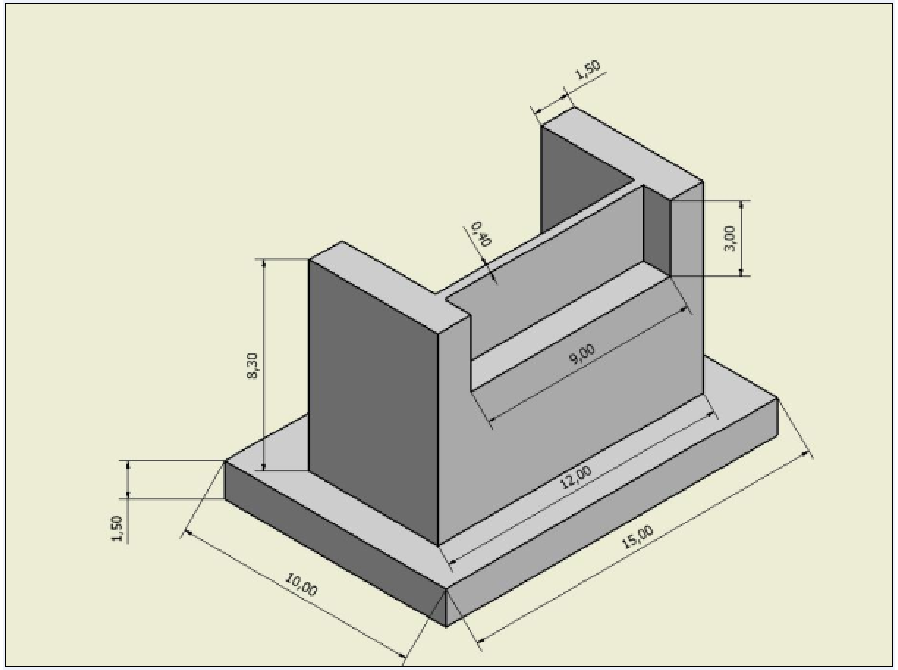
- $c'_{kg} = 0$
- $\varphi'_{kg} = 30°$
- $\gamma_{kg} = 20$ kN/m3

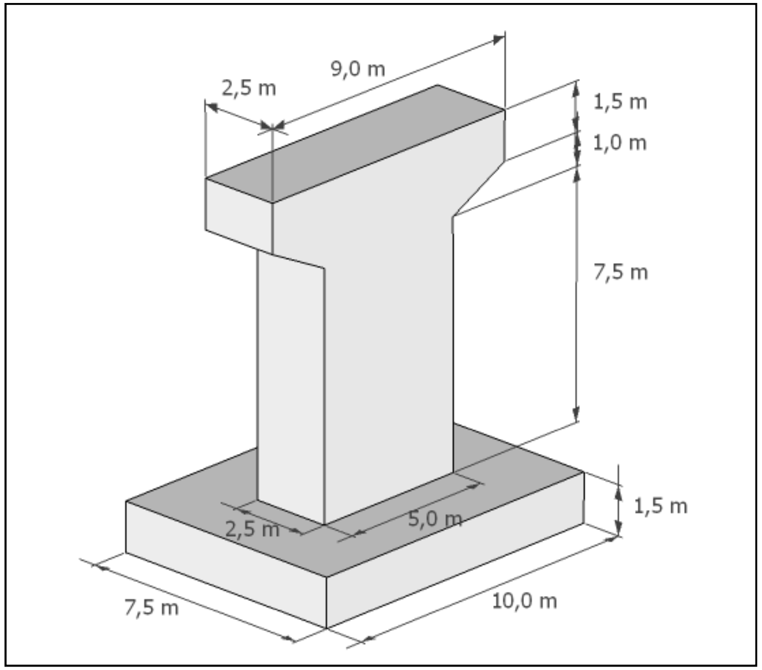
From ground level to base of foundation: $\gamma = 20 kN/m^3$

Water level is assumed to be one metre below the foundation level in both cases

Fill material : $c'_{kf} = 0$; $\varphi'_{kf} = 30°$; $\gamma_{kf} = 20 kN/m^3$

Abutment C0 and pier P1 (squat pier)





Pier P1 (squat pier)

- ULS - Bearing capacity (DA2 only)
- SLS – Settlement

P1 – ULS Bearing capacity

$G_{pier,k}$ = 8.3 MN

for DA2 :

$G_{pier,d}$ = 1.35 x 8.3 = 11.2 MN

At base of foundation :

$$F_v = V + G_{pier}$$
$$F_x = H_x$$
$$F_y = H_y$$
$$M_y = H_x h_p$$
$$M_x = H_y h_p$$

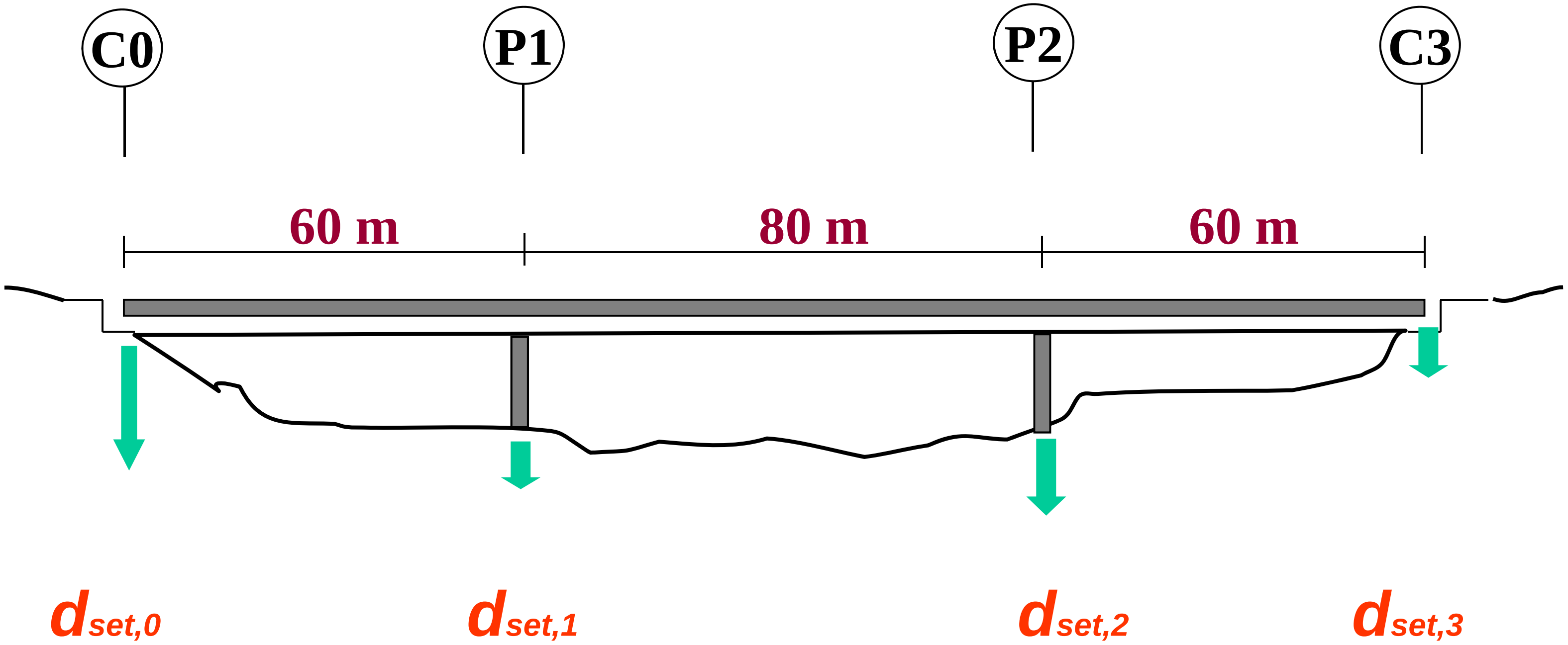
P1 – ULS Bearing capacity

For DA2 : F_{vd} = 28.9 + 11.2 = 40.1 MN
F_{xd} = 2.45 MN
F_{yd} = 0.68 MN

one obtains, for DA 2 :
e_B= 0.70 m, e_L = 0.20 m and R_k = 101.2 MN and
$R_d = R=/\gamma_{R;v}$ = 101.2/1.4 = 72.3 MN

The ULS condition in permanent and transient design situation $F_{vd} \leq R_d$ is fulfilled,
as 40.1 MN < 72.3 MN

ACTIONS : SETTLEMENTS



Theoretically, all possible combinations should be considered, but in most cases their effects are not critical for a bridge of that type.

P1 – SLS Settlement

SLS-QP combination:

Q = $G_{k,1}$ + $G_{k,2}$ = (5.2867 + 1.4665) x 2 = 6.75 x 2
= 13.5 MN

Ménard pressuremeter (MPM) method is used (Annex D2 of EN 1997-2)

The settlement is expressed as :

$$s = (q - \sigma_{v0}) \times \left[\frac{2B_0}{9E_d} \times \left(\frac{\lambda_d B}{B_0} \right)^a + \frac{\alpha \lambda_c B}{9E_c} \right]$$

P1 – SLS Settlement

$s = (0.18 - 0.06)\ [1.2\ (1.26 \text{x} 7.5/0.6)^{0.5} /(9 \text{x} 14.65) + 0.5 \text{x} 1.13 \text{x} 7.5/9 \text{x} 7.3]$

$= 0.12\ [0.036 + 0.065] = 0.012$ m = 12 mm ($d_{set,1}$),

(preliminary rough estimate, with $E_c = E_d = 6$ MPa $\sigma_{vo} = 0$: s = 0.030 m = 3 cm!)

Seismic design situations **(EN 1998-5)**

- no liquefiable layer – see Figs. 2 and 3

Annexes in Eurocode 8 – Part 5:

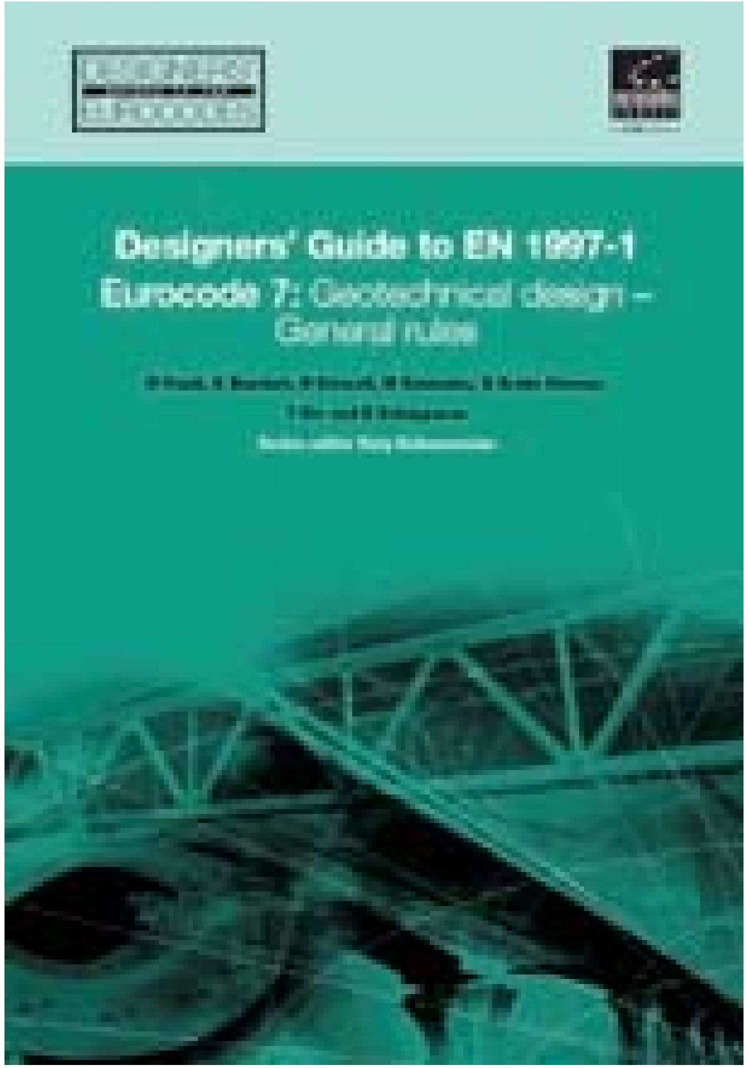
- Annex E (Normative) 'Simplified analysis for retaining structures',
- Annex F (Informative) 'Seismic bearing capacity of shallow foundations'

A_{ED} seismic action effects come from the capacity design of the superstructure (see Kolias 2010a and 2010b)

The recommended values of γ_M seem very conservative:
γ_{cu} = 1,4, $\gamma_{\tau cu}$ = 1,25, γ_{qu} = 1,4, and $\gamma_{\phi'}$ = 1,25.

The NA for Greece, for instance, requires : all γ = 1,0 !

One reference…



Some concluding comments

Eurocode 7 :

- a common language for the geotechnical engineers throughout Europe and on other continents…

- a necessary tool for the dialogue between the structural engineers and the geotechnical engineers

and to really conclude :

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 to fulfilling the fundamental requirements than is precision in the calculation models and partial factors

Thank you for your kind and patient attention !