EU-Russia Regulatory Dialogue: Construction Sector Subgroup

Seminar

"Worked examples on Bridge Design with Eurocodes"

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Geotechnical aspects of bridge design (EN 1997)

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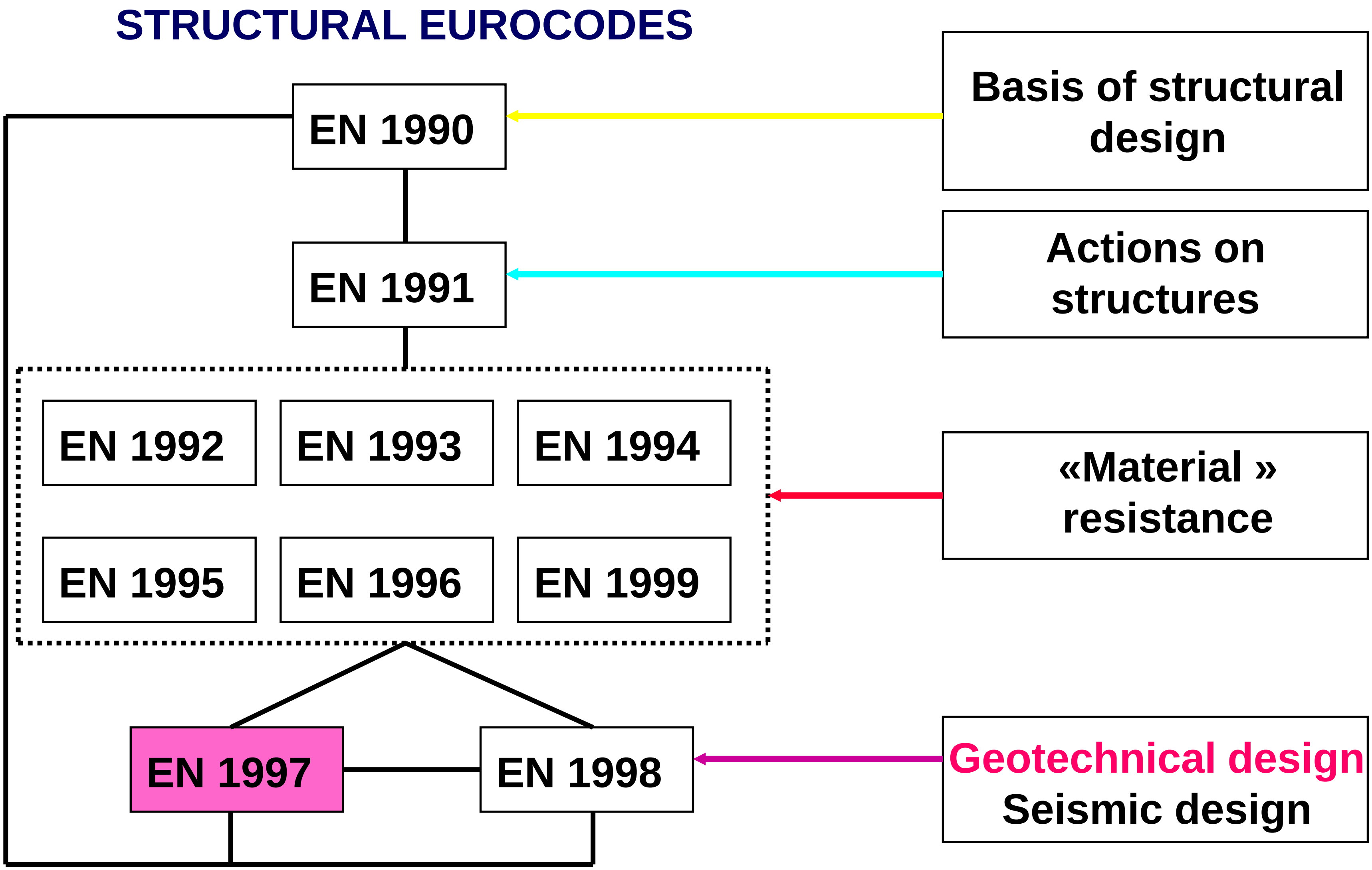
Contents

Introduction
Presentation of Eurocode 7 "Geotechnical design"
- Contents of Part 1 and 2
- Specific aspects of EN 1997-1
- Characteristic and design values
- ULS definition and check
- SLS and allowable movements of foundations
- Shallow foundations
- Design approaches
- Geotechnical data

Concluding remarks

Introduction



Introduction

GEOTECHNICAL DESIGN / ANALYSIS

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Checking all aspects of the interaction of a given structure and ground

Geotechnical analysis is responsible for

- assessing the ground nature and properties, including water,

- defining the ground resistance to any load (vertical, inclined, static, dynamic, seismic),

- estimating the ground deformation produced by the structure or any external action,

- defining the interaction forces at the ground-structure interface,

- checking the site stability and durability.

The aims of geotechnical analysis are the same in all countries.

NATIONAL EXPERIENCE AND EUROCODE 7

After a long (about 20 years) initial period trying to elaborate unified procedures, it was decided to produce an « umbrella » code giving rules but leaving details to national experience and preferences.

***An example*: The code says "You shall make a geotechnical model of the site interacting with the structure". But the way to achieve this is not imposed: you may use geology, geophysics, hydrogeology, in situ testing, core sampling and laboratory testing… depending on the way structures are calculated at the end. For resistances, some countries like pressuremeter or cone penetrometer, others like « c and φ ».**

EUROCODE 7 AND "DESIGN"

Eurocodes do not prescribe the type of structures nor their foundations.
This bridge might be founded on piles, a piled raft, shallow foundations.
Eurocodes define rules that have to be applied to prove the quality of the designed structure: loads and load combinations, criteria to be met by actions and resistances, provisions for safety assurance.
Eurocode 7 defines the rules for all actions and resistances linked to the ground (in combination with EC8 Part 5 for seismic situations).
For bridges, the loads are those transmitted by the structure to ground.

EUROCODE 7 AND "DESIGN"

The reason which incited me to fly to Casablanca then drive to Tangiers in Morocco last Saturday was the development of a landslide next to the bridge foundation. A decision had to be taken: close or do not close the highway?

Even if Eurocodes tell which conditions have to be met, they don't indicate how groups of piles function next to a landslide, which could eventually cross the bridge. The decision rely on the engineers understanding of nature.

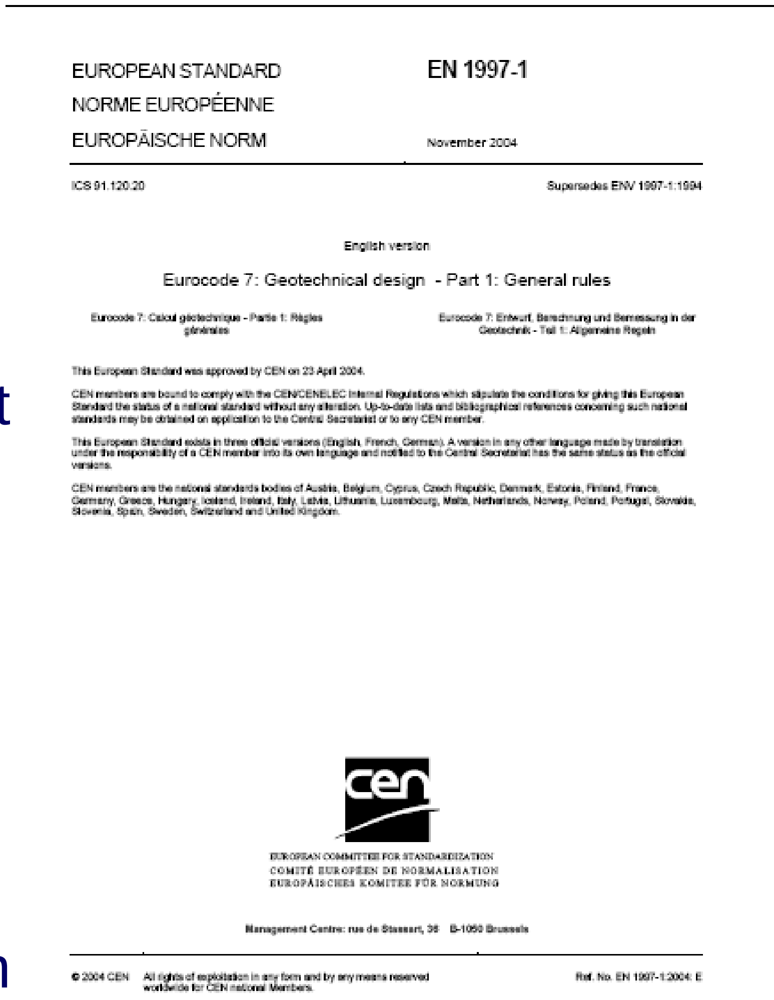
Eurocode 7 – Geotechnical design
(applied to buildings and bridges)

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

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

Contents of Part 1 (EN 1997-1:2004)

Section 1 General
Section 2 Basis of geotechnical design
Section 3 Geotechnical data
Section 4 Supervision of construction, monitoring and maintenance
Section 5 Fill, dewatering, ground improvement and reinforcement
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
Informative annexes with some calculation methods and recommended values of γ's



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.

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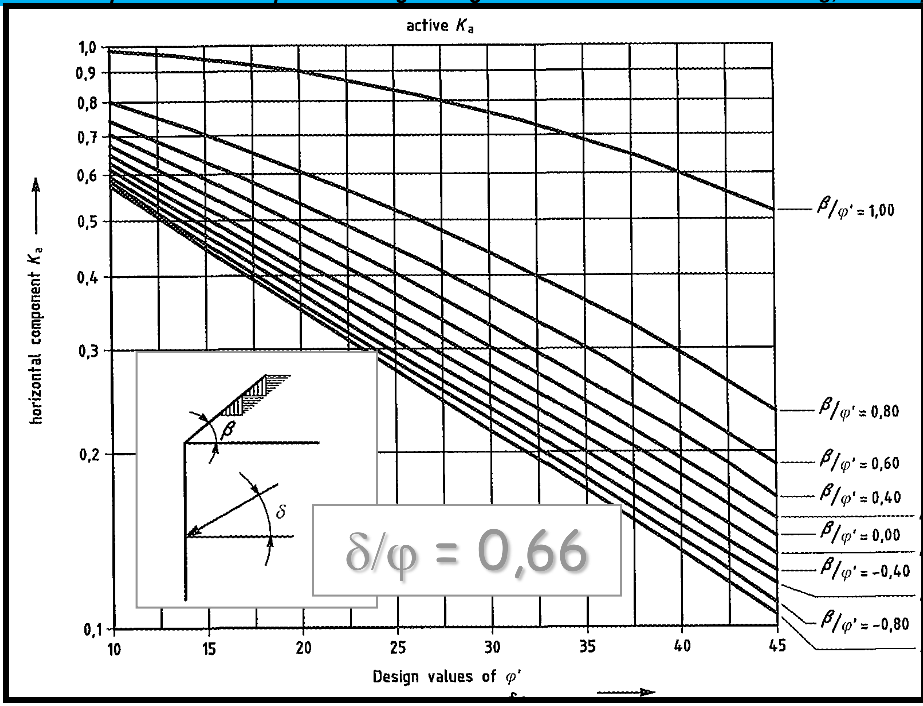
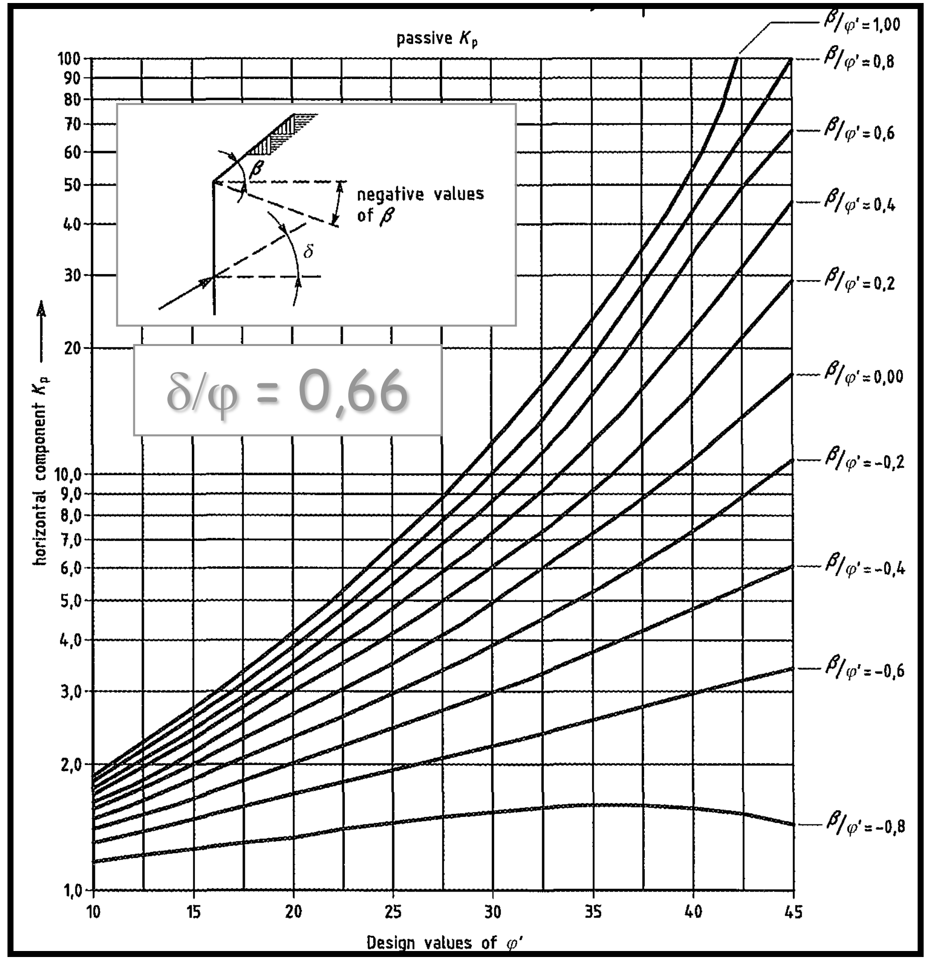
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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

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

Active /Passive earth pressures - annex C (Informative)





Active/Passive earth pressures

$\beta = -\varphi$ à $+\varphi$

$\delta = 0$; $2/3\varphi$ and φ

EN 1997-1 annexes D, E, F (Informative)
Bearing capacity and settlement of foundations

Ground resistance (footings)

"c-φ" model (Annex D)

$$R/A' = c' \times N_c \times b_c \times s_c \times i_c$$

$$+ q' \times N_q \times b_q \times s_q \times i_q$$

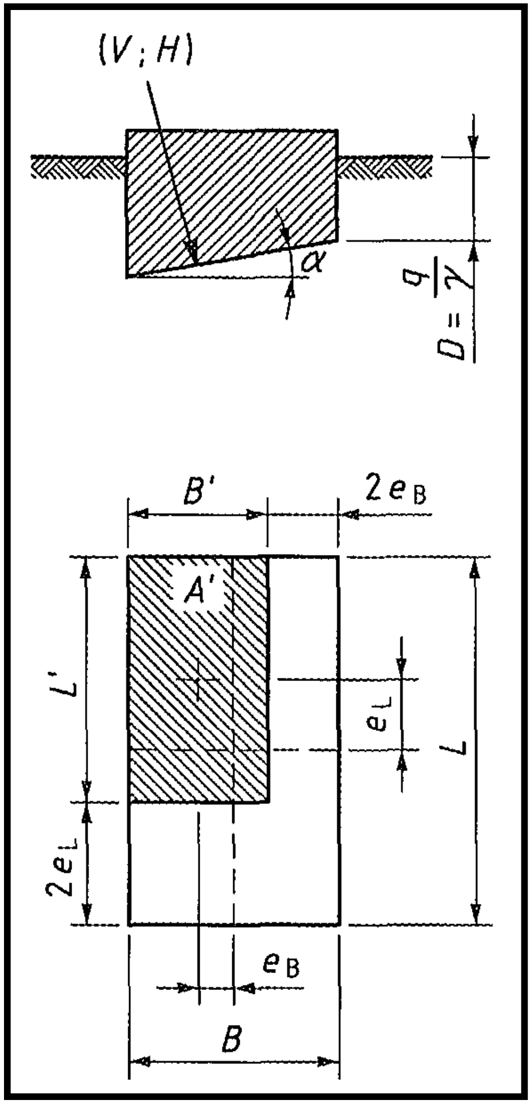
$$+ 0{,}5 \times \gamma' \times B' \times N_\gamma \times b_\gamma \times s_\gamma \times i_\gamma$$

Pressuremeter model (Annex E)

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

Settlement of footings (Annex F)

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



Contents of Part 2 (EN 1997-2:2007)

Section 1 General

Section 2 Planning and reporting of ground investigations

Section 3 Drilling, sampling and groundwater measurements

Section 4 Field tests in soils and rocks

Section 5 Laboratory tests on soils and rocks

Section 6 Ground investigation report

Informative annexes

(including calculation methods for piles)

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.

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 CEN Management Centre or to any CEN member.

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

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

Specific aspects of Eurocode 7-1

Characteristic values and design values

ULS and Design Approaches

SLS and deformations of structures

Characteristic values of geotechnical parameters

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. They are therefore dependant of the structure to be designed.

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%.

Comment: Characteristic values of ground properties are considered to be the same as the values previously used for geotechnical calculations.

Design values of geotechnical parameters

Design values are obtained from characteristic values by using partial factors:

Effects (E) of Actions (F) are

increased when unfavourable $E_d = E_k \gamma_E$ $(\gamma_E > 1)$,

decreased when favourable $E_d = E_k \gamma_E$ $(\gamma_E < 1)$.

Resistances R and soil strength X_{mat} are usually decreased:

$$R_d = R_k / \gamma_R$$

$$X_{mat,d} = X_{mat,k} / \gamma_M$$

Combinations of actions for the structure are accepted as there are defined by structural engineers (EN1900, EN1901).

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

(Fatigue is not considered)

Ultimate limit states – Eurocode 7-1

Limit states may be checked (avoided) by one or more of the following means:

— by calculation (section 2.4);
— by prescriptive measures (section 2.5);
— by testing models or load tests (section 2.6);
— by an observational method (section 2.7).

Checking stability by calculation

Design values of geotechnical parameters

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

Design values of effects of actions and resistances

Checking 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

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 $\gamma_M = 1.0$

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_p = lateral resistance)

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

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

STR/GEO Ultimate limit states (ULS contd)

Overall stability ("slope 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

Ultimate Limit States: design approaches

What are the values of all the "γ" for geotechnical design ?

1. The partial factors are meant to assure safety.
2. Safety cannot be invented and must be referred to experience.
3. Soil mechanics has always used one global factor applied to resistances, without increasing loads. Therefore, design forces (or pressures) at the interface of ground and structure are discontinuous since structural design usually increases them by 1.35 or more.
4. The continuity at ground-structure interface implies that 1.35 should be introduced in geotechnical design. Most of CEN members accepted that, but not all countries. Two types of analyses, named "design approaches", were then defined: Approach 1 specifies two parallel sets of calculations. Approach 2 (and approach 3, which differs by the position of partial factors) specifies only one set of calculations.

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 **New**	$\gamma_{R;v} = 1,0$ $\gamma_{R;h} = 1,0$
	1,0 and 1,3 **Traditional**	$\gamma_M = 1,25$ (on c' and tanφ') or $\gamma_M = 1,4$ (on c_u)
2	1,35 and 1,5 **New**	$\gamma_{R;v} = 1,4$ $\gamma_{R;h} = 1,1$
3	1,35 and 1,5 **New**	$\gamma_M = 1,25$ (on c' and tanφ') or $\gamma_M = 1,4$ (on c_u)

Experience (national) links safety to a minimum value of the ratio of resistances to loads.

Actions from structure

Actions from ground

Load
E_k

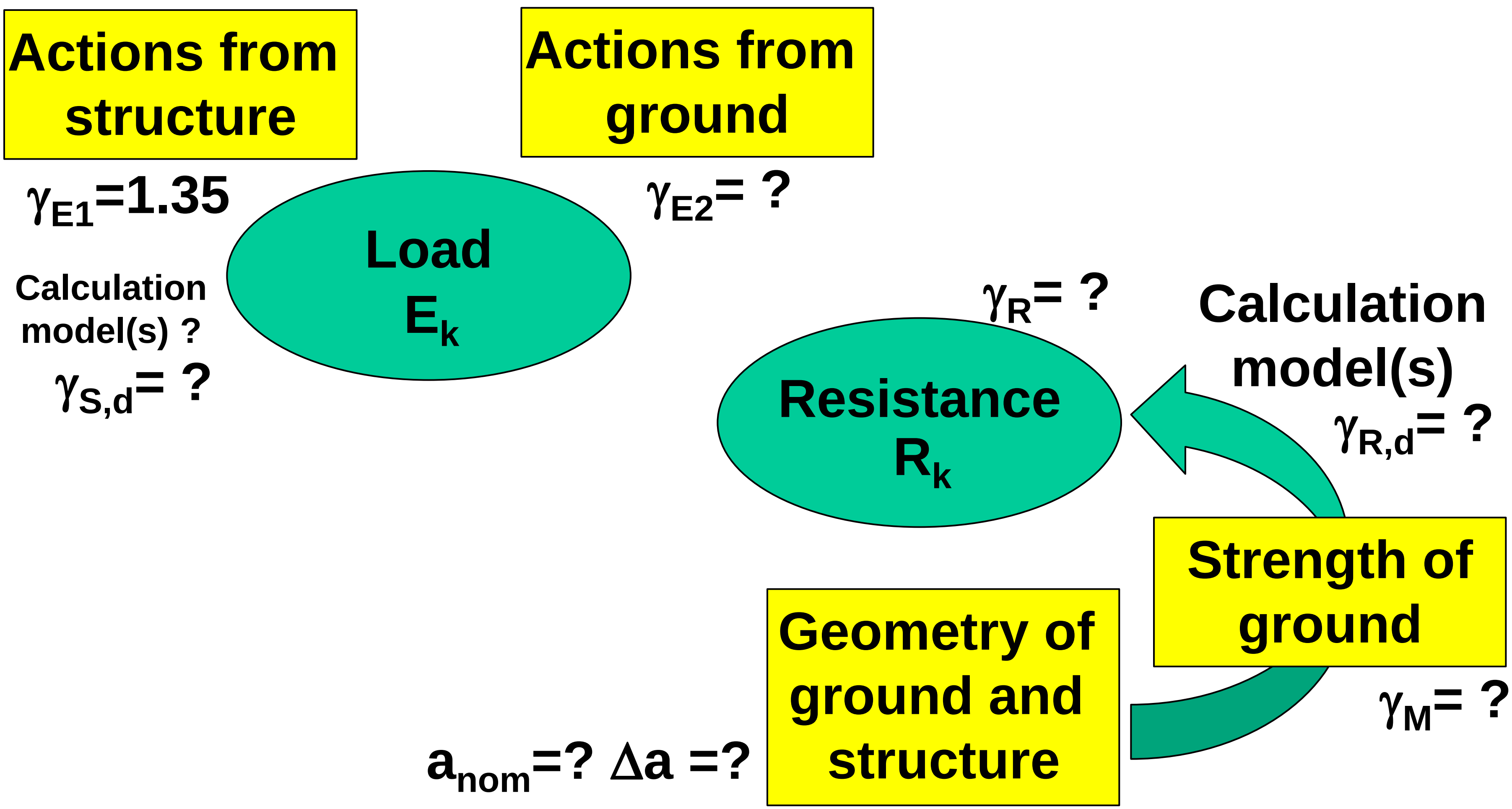
Resistance
R_k

Geometry of ground and structure

Strength of ground

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

Question: how to divide existing global factors into partial ones to get an equivalent result?



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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

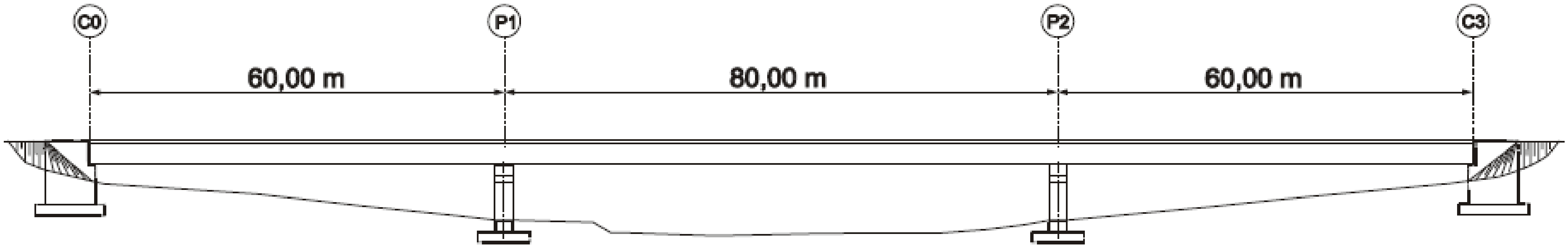
frequent questions to structural engineers : what are they?...

Bridge design

Bridge design

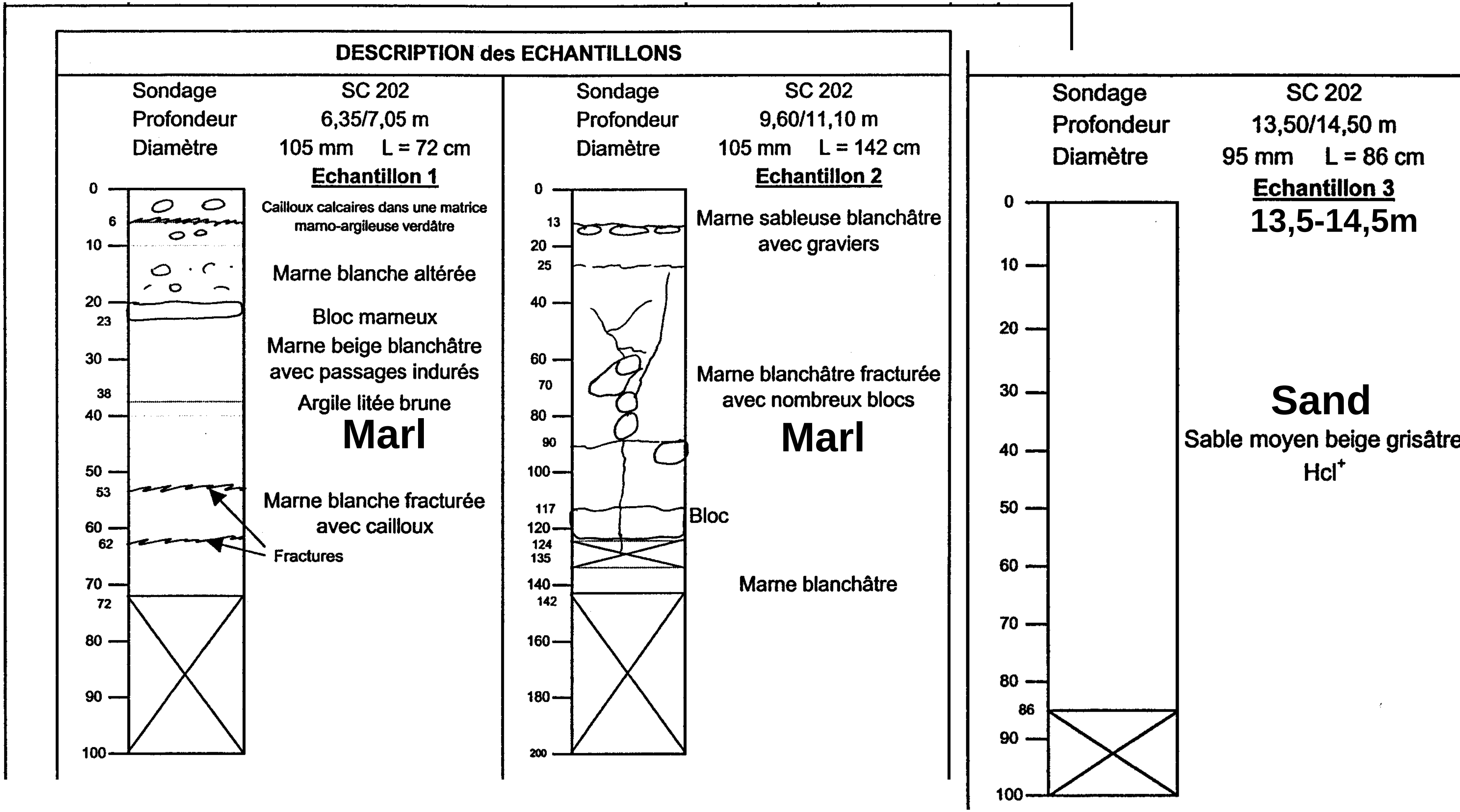
Bridge design

Bridge design



Geotechnical data: 10^{-6} to 10^{-8} of whole ground volume tested

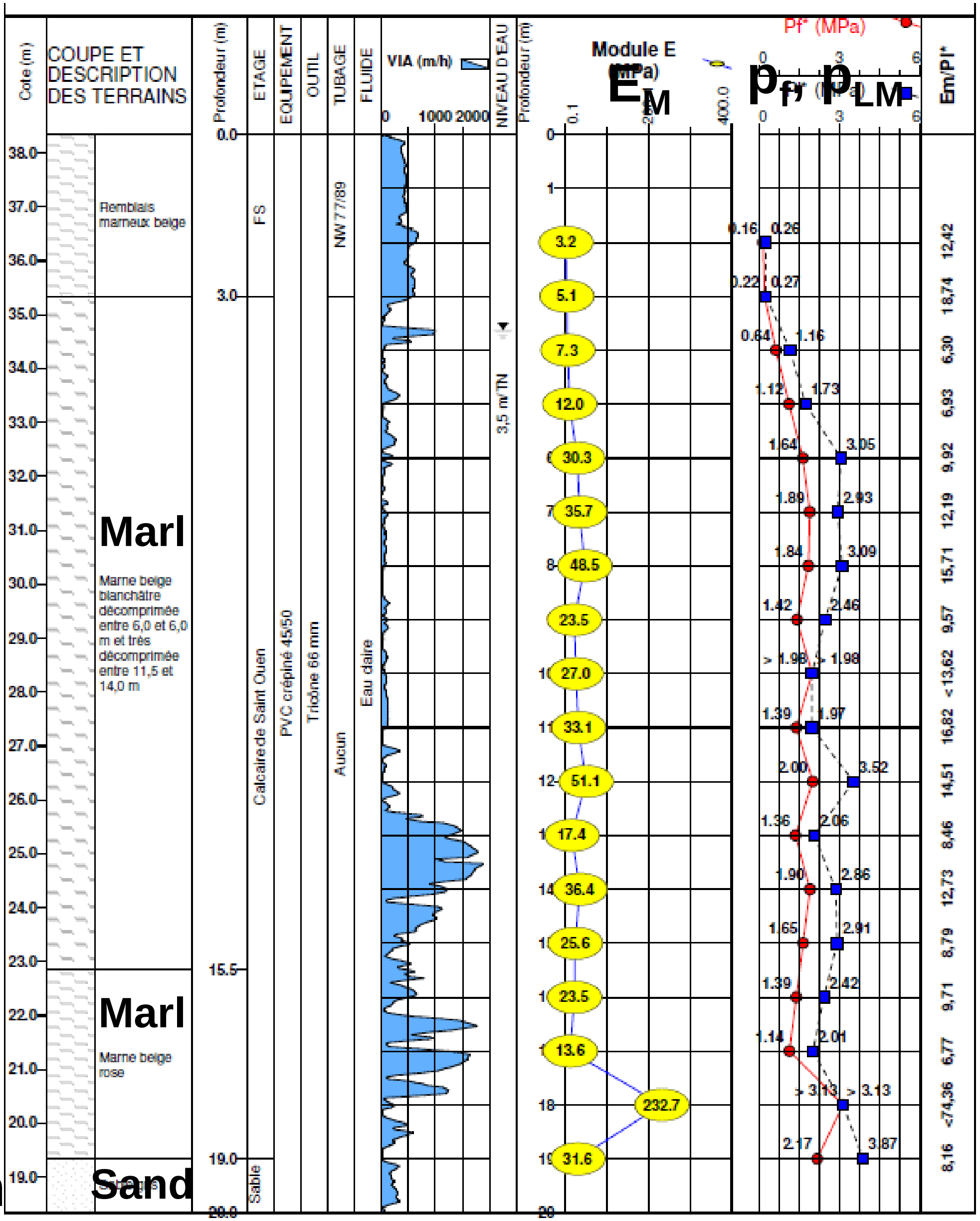
Geotechnical data



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

Geotechnical data

z=0m



z=20m

Results of pressuremeter tests between abutment C0 and pier P1

Geotechnical data for C0 and P1

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

- c'_{kg} = 0 kPa
- φ'_{kg} = 30 degrees
- γ_{kg} = 20 kN/m^3

From ground level to base of foundation: γ = 20kN/m^3

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

Fill material : c'_{kf} = 0; φ'_{kf} = 30 degrees; γ_{kf} = 20 kN/m^3

Some concluding comments

Eurocode 7 :

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

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

- yet geotechnical rules are mainly based on experience. Will the prevailing economic rules and the evolution of societies give the opportunity to further increase this experience ?

and to really conclude, Eurocode 7 states that:

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

&

1.3 "The code assumes that the personnel involved in all activities is suitably qualified and adequate communication exist among them"

Thank you for your attention !