European Commission

Ground investigation and testing: EN 1997-2

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Eurocode 7: Geotechnical design
Part 1: General rules

2.4 Geotechnical design by calculation

2.4.1 General

(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.

Contents of Eurocode 7-2

1. General
2. Planning of ground investigations
3. Soil and rock sampling and groundwater measurements
4. Field tests in soil and rock
5. Laboratory tests on soil and rock
6. Ground investigation report

23 Annexes

1.1.2 Scope of Eurocode 7-2

(1) EN 1997-2 is intended to be used in conjunction with EN 1997-1 and provides rules supplementary to EN 1997-1 related to:

- planning and reporting of ground investigations;
- general requirements for a number of commonly used laboratory and field tests;
- interpretation and evaluation of test results;
- derivation of values of geotechnical parameters and coefficients.

Note:

- Establishment of characteristic values is covered in EN 1997-1.

Hierarchy of standards

EC 7 *Geotechnical design* - part 2
Ground investigation and testing

- EN ISO 22476
  Field testing
  Part 1 to 13
- CEN ISO/TS 17892
  Laboratory tests
  Part 1 -12
- EN ISO 14688
  EN ISO 14689
  Identification and classification of soil and rock
- EN ISO 22475-1
  Sampling and groundwater measurements
  EN ISO 22475-2
  Sampling – Quali-fication criteria

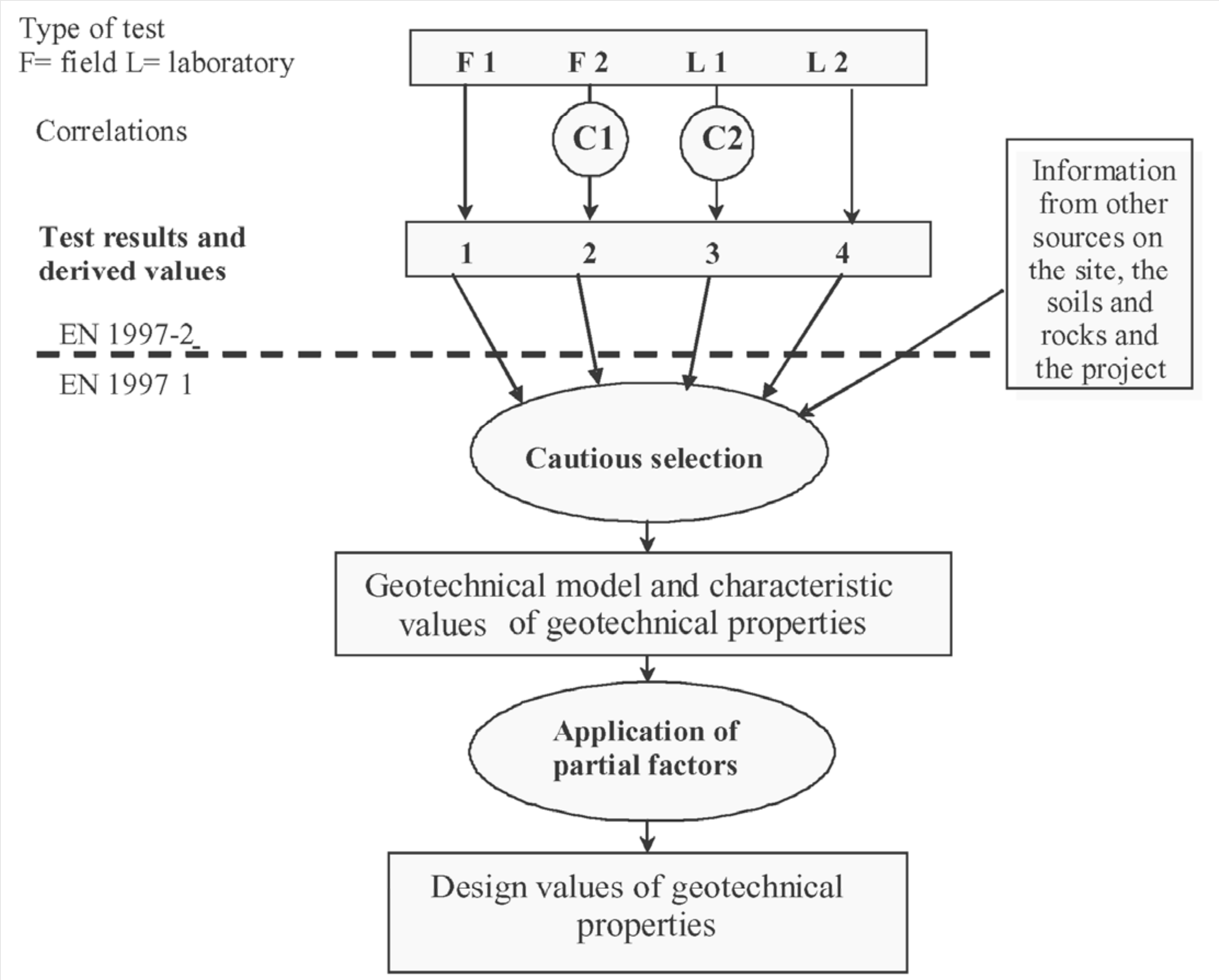
1.5 Definitions

1.5.3 Specific definitions used in EN 1997-2

1.5.3.1 derived value

value of a geotechnical parameter obtained from test results by theory, correlation or empiricism (see 1.6)

1.6 Test results and derived values



Content of Eurocode 7-2

1. General
2. **Planning of ground investigations**
3. Soil and rock sampling and groundwater measurements
4. Field tests in soil and rock
5. Laboratory tests on soil and rock
6. Ground investigation report

23 Annexes

2 Planning of ground investigations

2.1 Objectives

- 2.1.1 General
- 2.1.2 Ground
- 2.1.3 Construction materials
- 2.1.4 Groundwater

2.2 Sequence of ground investigations

2.3 Preliminary investigations

2.4 Design investigations

- 2.4.1 Field investigations
- 2.4.2 Laboratory tests

2.5 Controlling and monitoring

2.1 Objectives

2.1.1 General

(6) Before designing the investigation programme, the available information and documents should be evaluated in **a desk study**.

(7) Examples of information and documents that can be used are:

- geological maps and descriptions;
- previous investigations at the site and in the surroundings;
- aerial photos and previous photo interpretations;
- topographical maps;

2.1 Objectives

2.1.2 Ground

(1)P Ground investigations shall provide a description of ground conditions relevant to the proposed works and establish a basis for the assessment of the geotechnical parameters relevant for all construction stages.

(2) The information obtained should **enable assessment** of the following aspects, if possible:

- the suitability of the site with respect to the proposed construction and the level of acceptable risks;
- the deformation of the ground caused by the structure or resulting from construction works, its spatial distribution and behaviour over time;

2.1 Objectives

(2) The information obtained should enable **assessment** of the following aspects, if possible ***(continued)***:

- the safety with respect to **limit states** (e.g. subsidence, ground heave, uplift, slippage of soil and rock masses, buckling of piles, etc.);
- the **loads transmitted** from the ground to the structure (e.g. lateral pressures on piles) and the extent to which they depend on its design and construction;
- the **foundation methods** (e.g. ground improvement, whether it is possible to excavate, driveability of piles, drainage);
- the **sequence** of foundation works;

2.1 Objectives

(2) The information obtained should **enable assessment** of the following aspects, if possible (continued):

- the effects of the structure and its use on the **surroundings**;
- any **additional structural measures** required (e.g. support of excavation, anchorage, sleeving of bored piles, removal of obstructions); the effects of construction work on the surroundings;
- the type and extent of **ground contamination** on, and in the vicinity of, the site;
- the effectiveness of measures taken to contain or **remedy contamination**.

2.1 Objectives

2.1.4 Ground water

(3) The information obtained should be sufficient to **assess** the following aspects, <u>where relevant</u>:

- the scope for and nature of **groundwater-lowering work**;
- possible harmful effects of the groundwater on excavations or on slopes
- any measures necessary to **protect the structure**;
- the **effects of groundwater lowering**, desiccation, impounding etc. on the surroundings;
- the **capacity of the ground** to absorb water injected during construction work;
- whether it is possible to **use local groundwater**, given its chemical constitution, for construction purposes.

2.2 Sequence of ground investigations

Desk studies

Preliminary investigations

Design investigations

Supervision of construction (EC 7-1)

Controlling and monitoring (EC 7-1)

2.4 Design investigations

2.4.1.3 Locations and depths of the investigation points

(2) When selecting the locations of investigation points, the following should be observed:

- the investigation points should be arranged in such a pattern that the **stratification** can be assessed across the site;
- the investigation points for a building or structure should be placed at **critical points** relative to the shape, structural behaviour and expected load distribution (e.g. at the corners of the foundation area);
- for linear structures, investigation points should be arranged at **adequate offsets** to the centre line, depending on the overall width of the structure, such as an embankment footprint or a cutting;

2.4 Design investigations

2.4.1.3 Locations and depths of the investigation points

(2) When selecting the locations of investigation points, the following should be observed (continued):

- for structures on or near slopes and steps in the terrain (including excavations), investigation points should also be arranged outside the project area, these being located so that the **stability of the slope** or cut can be assessed.
- Where **anchorages** are installed, due consideration should be given to the likely stresses in their load transfer zone;
- the investigation points should be arranged so that they do **not present a hazard** to the structure, the construction work, or the surroundings (e.g. they may cause changes to the ground and groundwater conditions);

2.4 Design investigations

2.4.1.3 Locations and depths of the investigation points

(2) When selecting the locations of investigation points, the following should be observed (continued):

- the area considered in the design investigations should extend into the neighbouring area to a distance where **no harmful influence on the neighbouring** area is expected;
- for **groundwater** measuring points, the possibility of using the equipment installed during the ground investigation for **continued monitoring** during and after the construction period should be considered.

2.4 Design investigations

(6)P The **depth of investigations** shall be extended to all strata that will affect the project or are affected by the construction.

- For dams, weirs and excavations below groundwater level, and where dewatering work is involved, the depth of investigation shall also be selected as a function of the hydro-geological conditions.
- For slopes and steps in the terrain shall be explored to depths below any potential slip surface.

NOTE For the **spacing** of investigation points and investi-gation **depths**, the values given in Annex B.3 can be used as guidance.

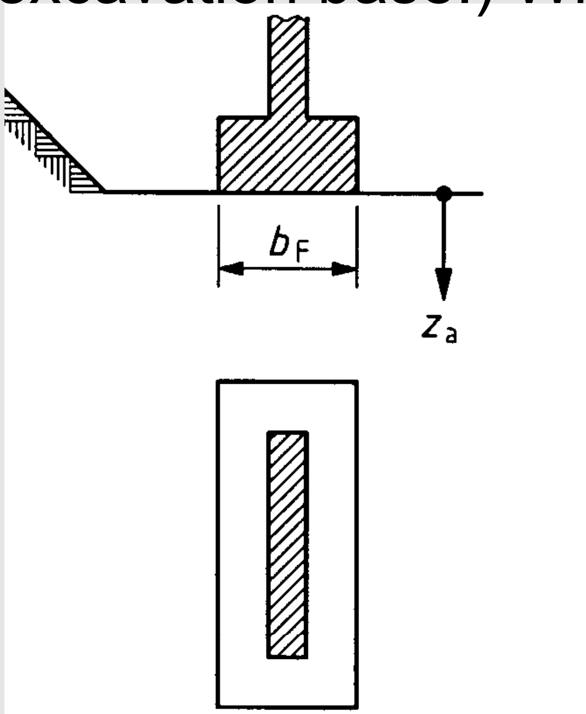
Annex B.3 (informative)
Examples of recommendations for the spacing and depth of investigations

(1) The following spacing of investigation points should be used as guidance:

- for high-rise and industrial structures, a grid pattern with points at **15 m to 40 m** distance;
- for large-area structures, a grid pattern with points at not more than **60 m** distance;
- for linear structures (roads, railways, channels, pipelines, dikes, tunnels, retaining walls), a spacing of **20 m to 200** m;
- for special structures (e.g. bridges, stacks, machinery foundations), **two to six** investigation points per foundation;
- for dams and weirs, **25 m to 75 m** distance, along vertical sections.

B.3: Spacing and depth of investigations

(2) For the investigation **depth z_a** the following values should be used as guidance. (The reference level for z_a is the lowest point of the foundation of the structure or structural element, or the excavation base.) Where more than one alternative is specified for establishing z_a, the one which yields the largest value should be applied.

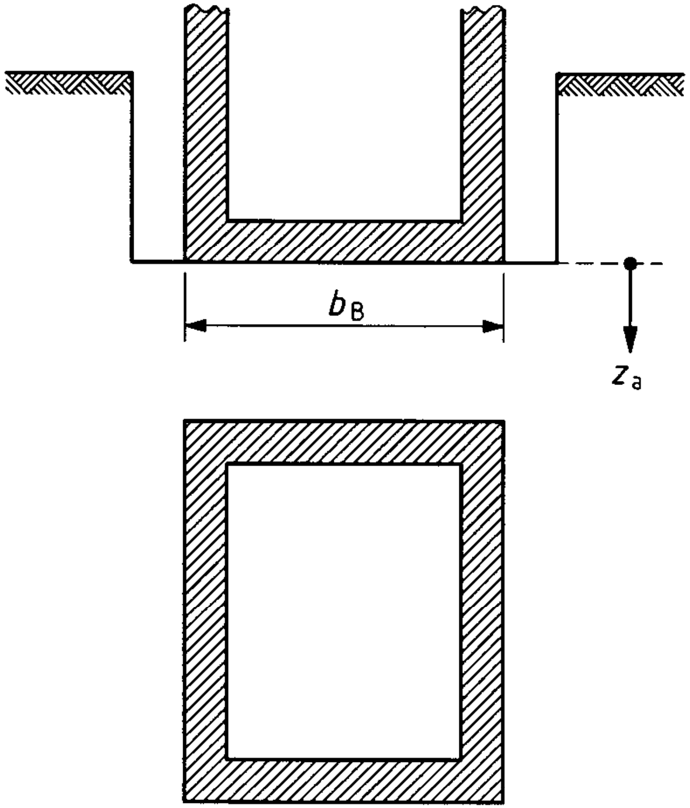


(5) For **high-rise structures** and civil engineering projects, the larger value of the following conditions should be applied:

- $z_a \geq 6$ m;
- $z_a \geq 3{,}0\, b_F$.

where b_F is the smaller side length of the foundation.

Annex B.3: Spacing and depth of investigations

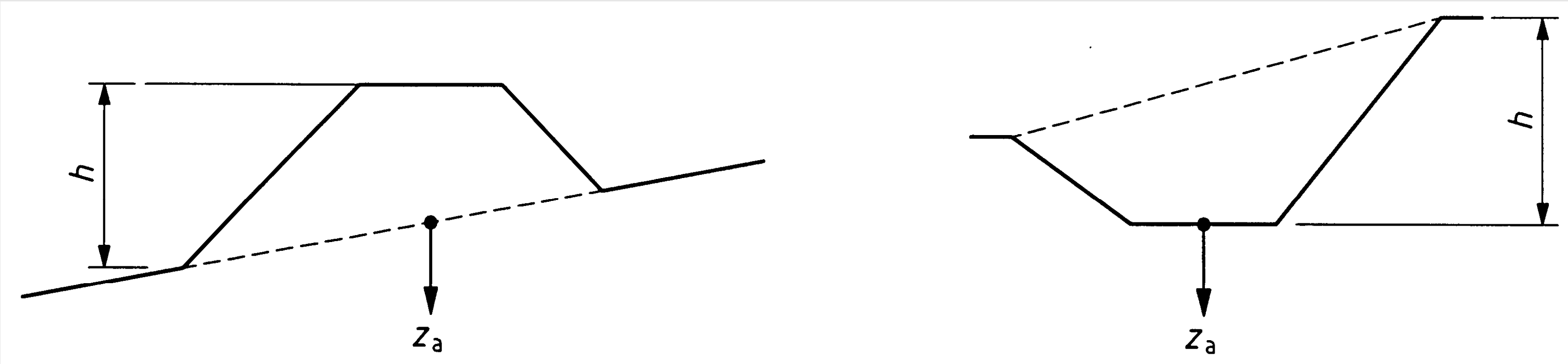


(6) For **raft foundations** and structures with several foundation elements whose effects in deeper strata are superimposed on each other:

$z_a \geq 1{,}5 \cdot b_B$

where b_B is the smaller side of the structure,

Annex B.3: Spacing and depth of investigations



(7) **Embankments** and **cuttings**, the larger value of the following conditions should be met:

a) For dams:

− $0{,}8h < z_a < 1{,}2h$

− $z_a \geq 6$ m

where *h* is the embankment height.

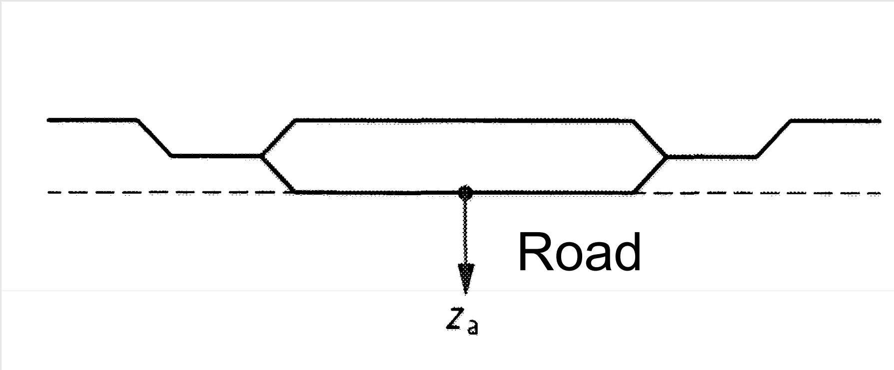
b) For cuttings:

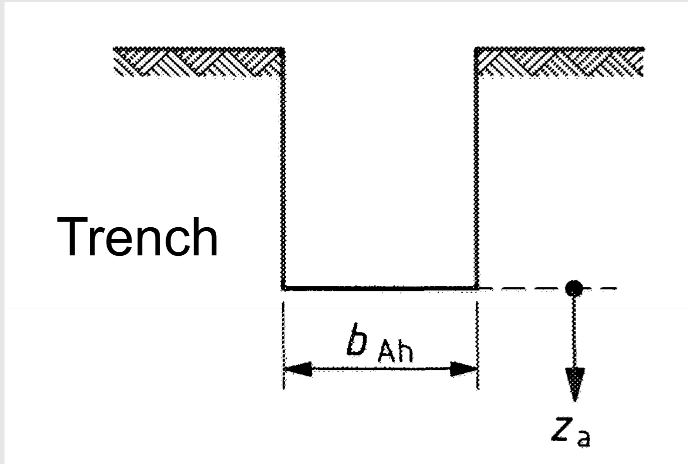
− $z_a \geq 2{,}0$ m

− $z_a \geq 0{,}4h$

where *h* is the dam height or depth of cutting.

Annex B.3: Spacing and depth of investigations

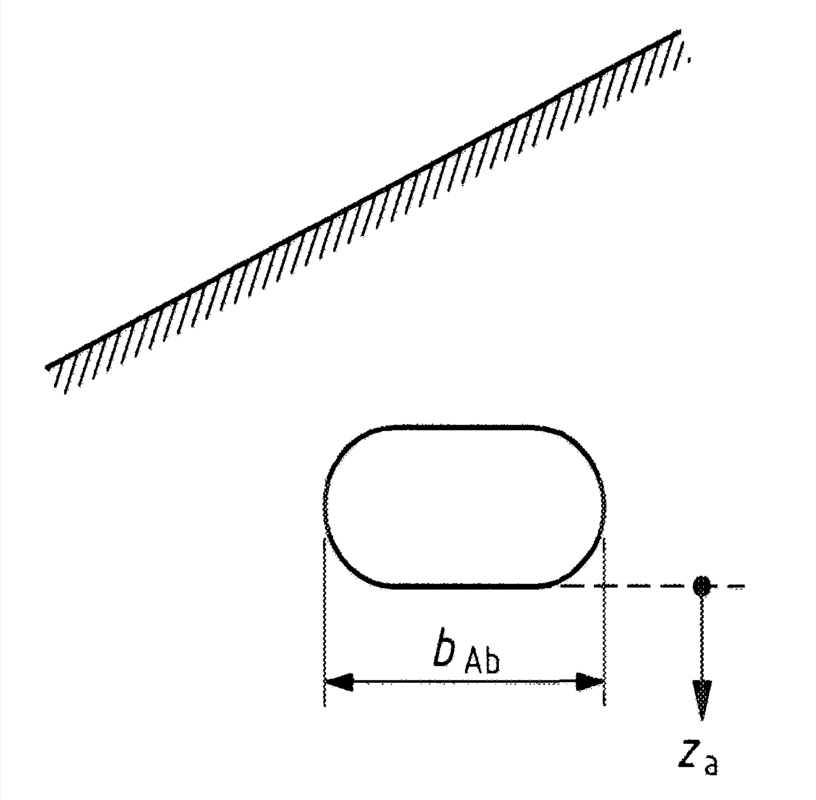




For **roads** and **airfields**:
$z_a \geq 2$ m below the proposed formation level.

For **trenches** and pipelines, the larger value of:
− $z_a \geq 2$ m below the invert level;
− $z_a \geq 1{,}5 b_{Ah}$
where b_{Ah} is the width of excavation.

Annex B.3: Spacing and depth of investigations



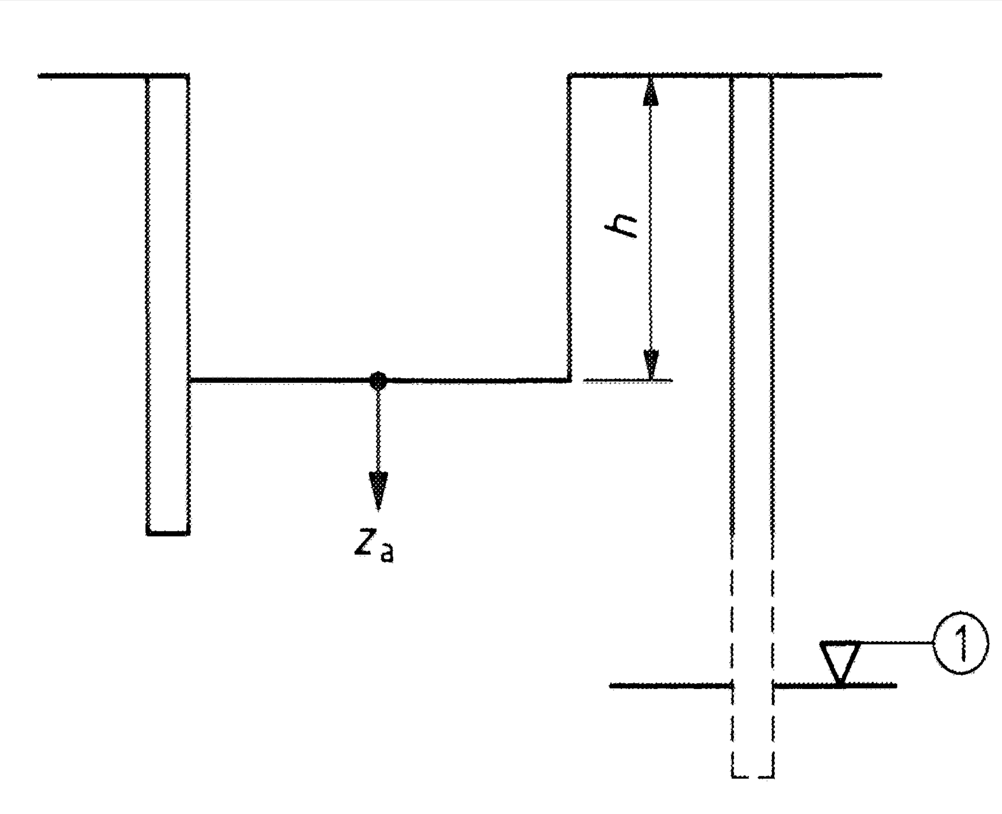
(9) For **small tunnels and caverns:**

$b_{Ab} < z_a < 2{,}0 b_{Ab}$

where b_{Ab} is the width of excavation.

The groundwater conditions described in (10) b) should also be taken into account.

Annex B.3: Spacing and depth of investigations



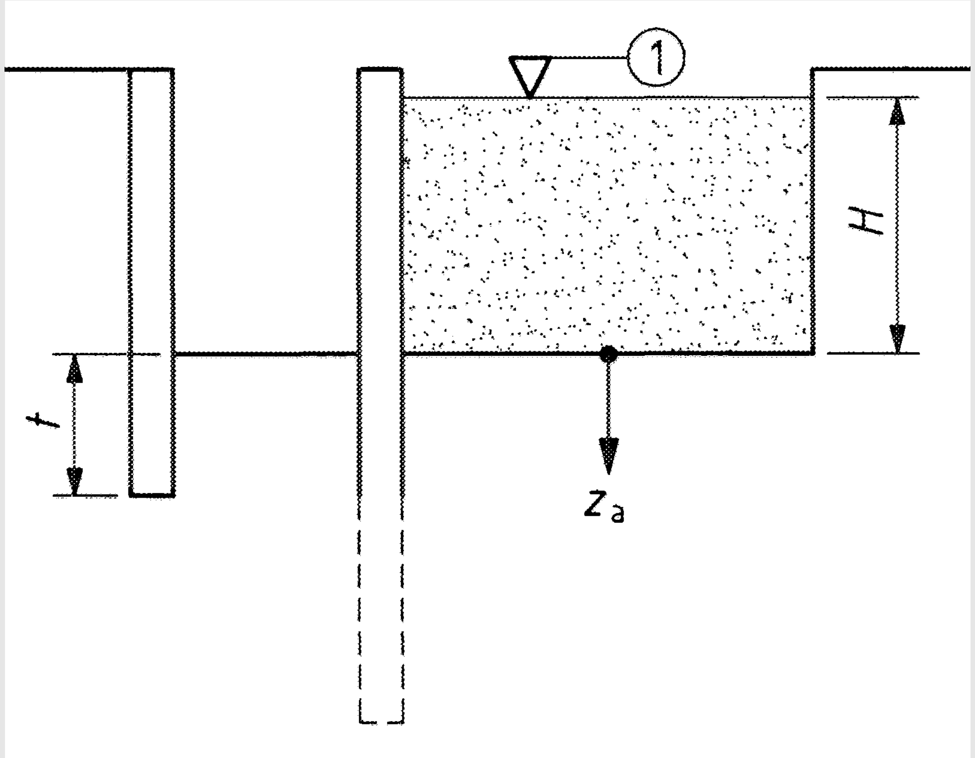
(10) **Excavations** a) Where the piezometric surface and the groundwater tables are **below the excavation** base, the larger value of the following conditions should be met:

− $z_a \geq 0{,}4h$

− $z_a \geq (t + 2{,}0)$ m

where: t is the embedded length of the support; and h is the excavation depth.

Annex B.3: Spacing and depth of investigations



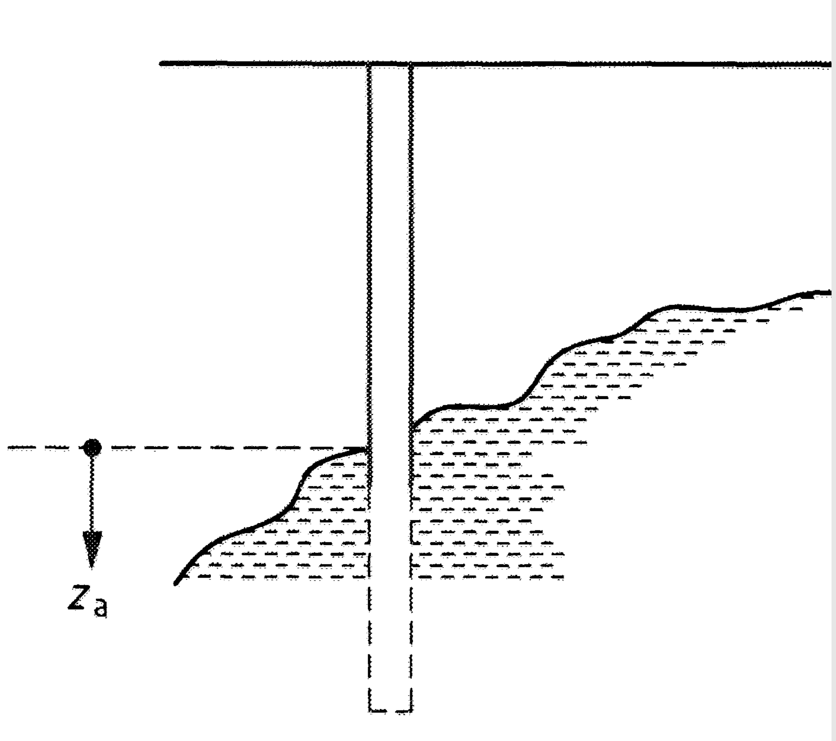
b) Where the piezometric surface and the **groundwater tables** are **above the excavation base**, the larger value of the following conditions should be met:

− $z_a \geq (1{,}0 \cdot H + 2{,}0)$ m

− $z_a \geq (t + 2{,}0)$ m

where H is the height of the groundwater level above the excavation base; and t is the embedded length of the support.

Annex B.3: Spacing and depth of investigations

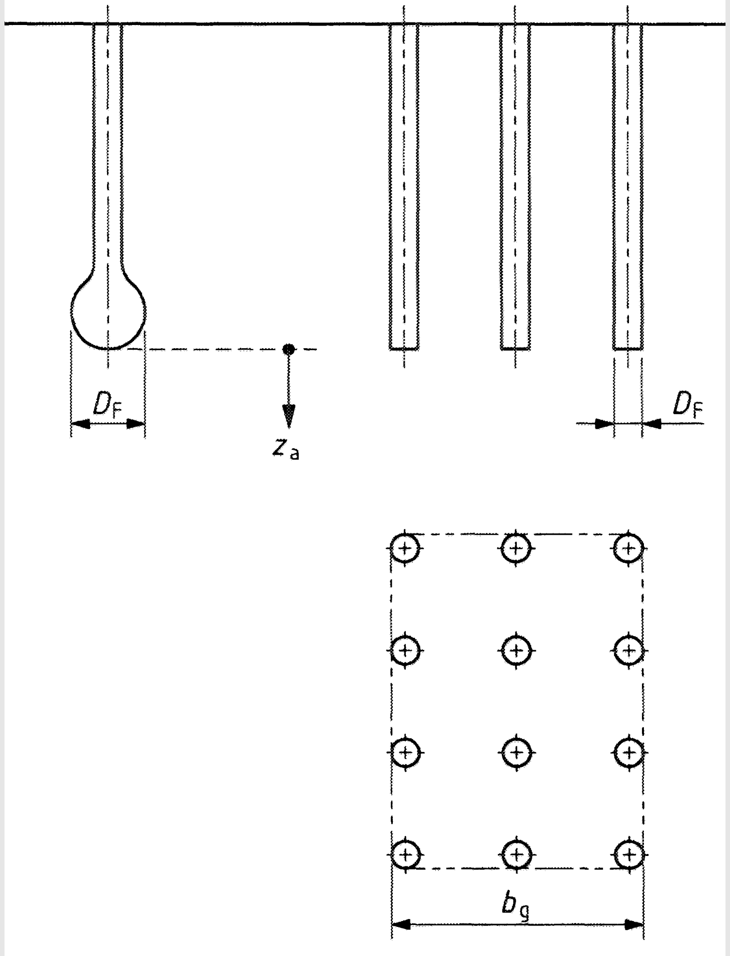


(12) For **cut-off walls**:

– $z_a \geq 2$ m

below the surface of the stratum impermeable to groundwater.

Annex B.3: Spacing and depth of investigations



(13) For **piles** the following three conditions should be met:

− $z_a \geq 1{,}0 b_g$

− $z_a \geq 5{,}0$ m

− $z_a \geq 3D_F$

where D_F is the pile base diameter; and b_g is the smaller side of the rectangle circum-scribing the group of piles forming the foundation at the level of the pile base.

2 Planning of ground investigations

2.4.1.4 Sampling

(2)P For identification and classification of the ground, at least **one borehole or trial** pit with sampling shall be available. Samples shall be obtained from **every separate ground layer influencing** the behaviour of the structure.

(3) **Sampling may be replaced by field tests** if there is enough local experience to correlate the field tests with the ground conditions to ensure unambiguous interpretation of the results.

(7) Samples should be taken **at any change of stratum** and at a specified spacing, usually not larger than **3 m**. In inhomogeneous soil, or if a detailed definition of the ground conditions is required, continuous sampling by drilling should be carried out or samples recovered at very short intervals.

3 Soil and rock sampling and groundwater measurements

3.1 General

3.2 Sampling by drilling

3.3 Sampling by excavation

3.4 Soil sampling

3.5 Rock sampling

3.6 Groundwater measurements in soils and rocks

3.4 Soil sampling

(1)P Samples shall contain **all the mineral constituents** of the strata from which they have been taken. They shall not be contaminated by any material from other strata or from additives used during the sampling procedure.

(2)P **Three sampling method categories** shall be considered (EN ISO 22475-1), depending on the desired sample quality as follows:

- **category A** sampling methods: samples of quality class 1 to 5 can be obtained;
- **category B** sampling methods: samples of quality class 3 to 5 can be obtained;
- **category C** sampling methods: only samples of quality class 5 can be obtained.

3.4 Soil sampling

(6)P Soil samples for laboratory tests are divided in **five quality classes** with respect to the soil properties that are assumed to **remain unchanged** during sampling and handling, transport and storage.

Table 3.1 - Quality classes of soil samples for laboratory testing and sampling categories to be used

Soil properties / quality class	**1**	**2**	**3**	**4**	**5**
Unchanged soil properties					
particle size	*	*	*	*	
water content	*	*	*		
density, density index, permeability	*	*			
compressibility, shear strength	*				
Properties that can be determined:					
sequence of layers	*	*	*	*	*
boundaries of strata – broad	*	*	*	*	
boundaries of strata – fine	*	*	*	*	
Atterberg limits, particle density, organic content	*	*	*		
water content	*	*			
density, density index, porosity, permeability	*	*			
compressibility, shear strength	*				
Sampling category according to EN ISO 22475-1	A				
			B		
					C

4 Field tests in soil and rock

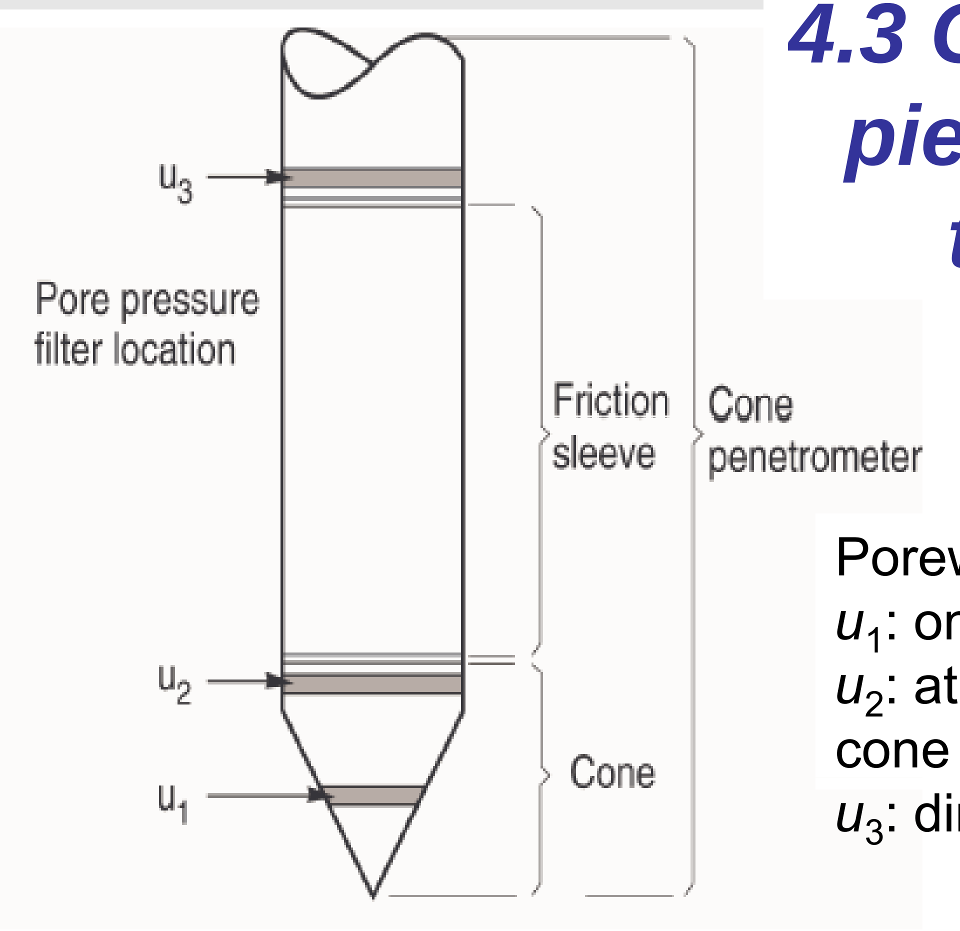
4.1 General
4.2 General requirements
4.3 Cone penetration and piezocone penetration tests (CPT, CPTU)
4.4 Pressuremeter tests (PMT)
4.5 Flexible dilatometer test (FDT)
4.6 Standard penetration test SPT
4.7 Dynamic probing tests (DP)
4.8 Weight sounding test (WST)
4.9 Field vane test (FVT)
4.10 Flat dilatometer test (DMT)
4.11 Plate loading test (PLT)

4.3 Cone penetration tests

(1) The objective of the cone penetration test (CPT) is to determine the resistance of soil and soft rock to the penetration of a cone and the local friction on a sleeve.

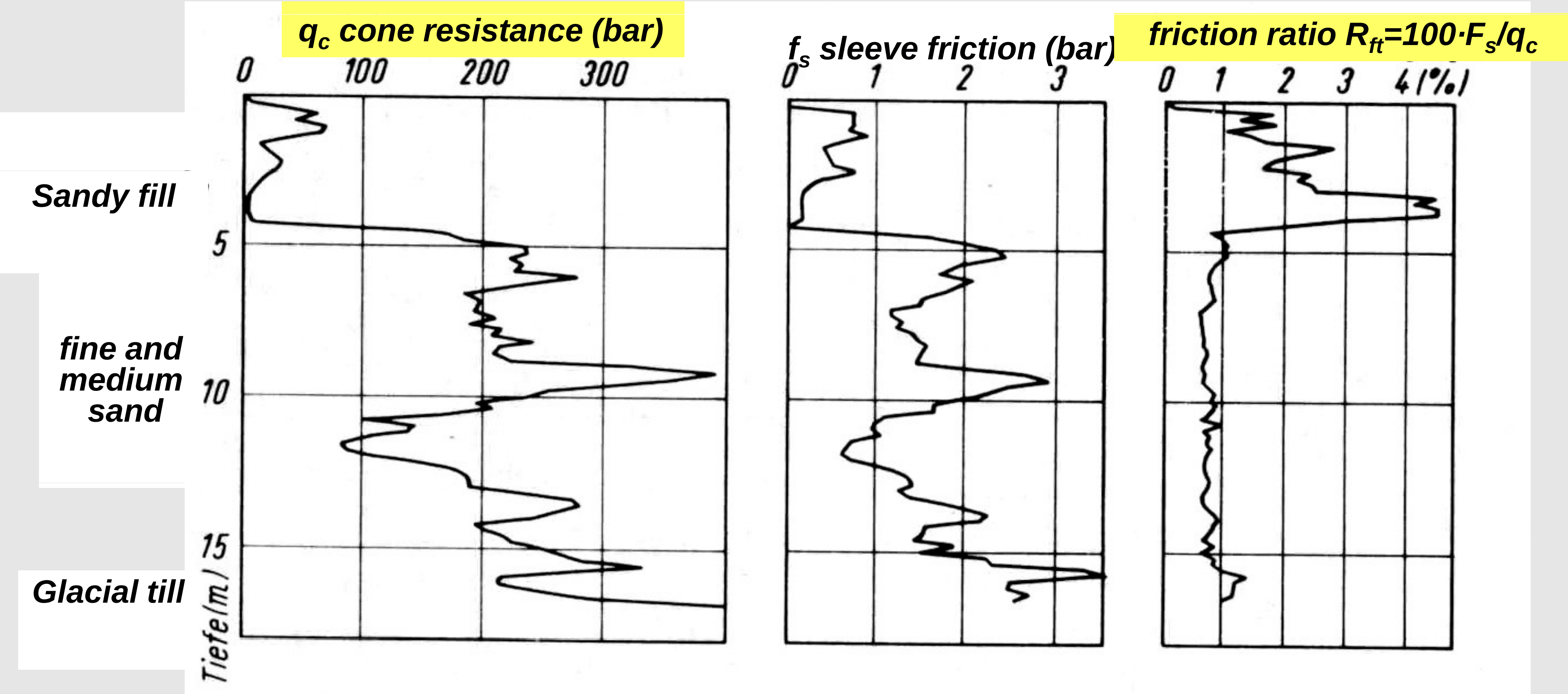
(2)P The CPT consists of pushing a cone penetrometer vertically into the soil using a series of push rods. The cone penetrometer shall be pushed into the soil at a constant rate of penetration. The cone penetrometer comprises the cone and if appropriate a cylindrical shaft or friction sleeve. The penetration resistance of the cone q_c as well as, if appropriate, the local friction on the friction sleeve shall be measured.

4.3 Cone penetration and piezocone penetration tests (CPT, CPTU)



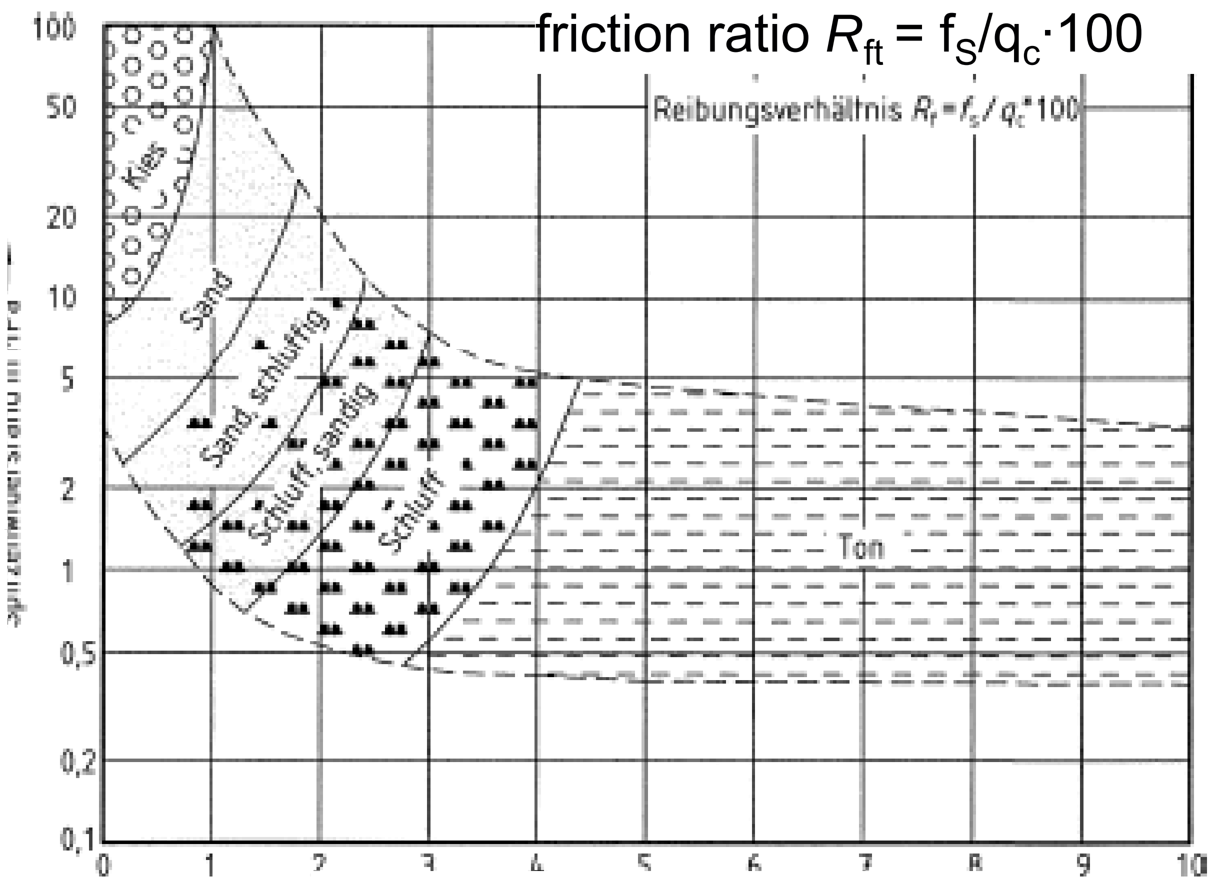
Porewater pressure measurement:
u_1: on the cone face
u_2: at the cylindrical extension of the cone
u_3: directly behind the friction sleeve

4.3 Cone penetration and piezocone penetration tests (CPT, CPTU)



4.3 Cone penetration tests

q_c cone penetration resistance



friction ratio $R_{ft} = f_S/q_c \cdot 100$

4.3 Cone penetration tests - Annex D

D.1 Example for deriving values of the **effective angle of shearing resistance** and **drained Young's modulus**

D.2 Example of a correlation between the cone penetration resistance and the effective angle of shearing resistance

D.3 Example of a method to determine the **settlement for spread foundations**

D.4 Example of a correlation between the **oedometer modulus** and the cone penetration resistance

D.5 Examples of establishing the stress-dependent oedometer modulus from CPT results

D.6 Example of a correlation between compressive resistance of a **single pile** and cone penetration resistance

D.7 Example of a method to determine the compressive resistance of a single pile.

Annex D.1 (informative)

Table D.1: Effective angle of shearing resistance (φ') and drained Young's modulus of elasticity (E') from cone penetration resistance (q_c)

Density index	Cone resistance (q_c) (from CPT) MPa	Effective angle of shearing resistance[a], (φ') °	Drained Young's modulus[b], (E') MPa
Very loose	0,0 – 2,5	29 – 32	< 10
Loose	2,5 – 5,0	32 – 35	10 – 20
Medium dense	5,0 – 10,0	35 – 37	20 – 30
Dense	10,0 – 20,0	37 – 40	30 – 60
Very dense	> 20,0	40 – 42	60 – 90

a Values given are valid for sands. For silty soil a reduction of 3° should be made. For gravels 2° should be added.

b *E*' is an approximation to the stress and time dependent secant modulus. Values given for the drained modulus correspond to settlements for 10 years. They are obtained assuming that the vertical stress distribution follows the 2:1 approximation.

5 Laboratory tests

5.1 General
5.2 General requirements for laboratory tests
5.3 Preparation of soil specimens for testing
5.4 Preparation of rock specimens for testing
5.5 Tests for classification, identification and description of soil
5.6 Chemical testing of soil and groundwater
5.7 Strength index testing of soil
5.8 Strength testing of soil
5.9 Compressibility and deformation testing of soil
5.10 Compaction testing of soil
5.11 Permeability testing of soil
5.12 Tests for classification of rocks
5.13 Swelling testing of rock material
5.14 Strength testing of rock material

Table P.1 – Triaxial compression tests. Recommended minimum number of tests for one soil stratum

Recommended number of tests to determine the effective angle of shearing resistance [a]			
Variability in strength envelope Coefficient of correlation r on regression curve	Comparable experience		
	None	Medium	Extensive
$r \leq 0{,}95$	4	3	2
$0{,}95 << r \leq 0{,}98$	3	2	1
$r \geq 0{,}98$	2	1	1
Recommended number of tests to determine the undrained shear strength [a]			
Variability in undrained shear strength (for same consolidation stress)	Comparable experience		
	None	Medium	Extensive
Ratio max/min values > 2	6	4	3
1,25 < Ratio max/min value ≤ 2	4	3	2
Ratio max/min value ≤ 1,25	3	2	1

[a] One recommended test means a set of three individual specimens tested at different cell pressures.

Table Q.1 — Incremental oedometer test. Recommended minimum number of tests for one soil stratum

Variability in oedometer modulus E_{oed}	Comparable experience		
(in the relevant stress range)	None	Medium	Extensive
Range of values of $E_{oed} \geq 50$ %	4	3	2
20 % < Range of values of $E_{oed} < 50$ %	3	2	2
Range of values of $E_{oed} \leq 20$ %	2	2	1[a]
[a] One oedometer test and classification tests to verify compatibility with comparable knowledge (see Q.1 (2)).			

Table S.1 - Permeability tests. Recommended minimum number of soil specimens to be tested for one soil stratum.

Variability in measured coefficient of permeability (*k*)	Comparable experience		
	None	**Medium**	**Extensive**
$k_{max}/k_{min} > 100$	5	4	3
$10 < k_{max}/k_{min} \leq 100$	5	3	2
$k_{max}/k_{min} \leq 10$	3	2	1[a]
[a] A single test and classification tests to verify compatibility with existing knowledge.			

6 Ground investigation report

6.1 General requirements

6.2 Presentation of geotechnical information

6.3 Evaluation of geotechnical information

6.4 Establishment of derived values

6 Ground investigation report

6.1 General requirements

(1)P The results of a geotechnical investigation shall be compiled in the Ground Investigation Report which shall form a part of the Geotechnical Design Report.

(2)P The Ground Investigation Report shall consist of, if appropriate

- a presentation of all available geotechnical information including geological features and relevant data;
- a geotechnical evaluation of the information, stating the assumptions made in the interpretation of the test results.

6 Ground investigation report

6.2 Presentation of geotechnical information

(1)P The presentation of geotechnical information shall include a factual account of all field and laboratory investigations.

(2) The factual account should include the following information, as relevant:

- .....
- ....

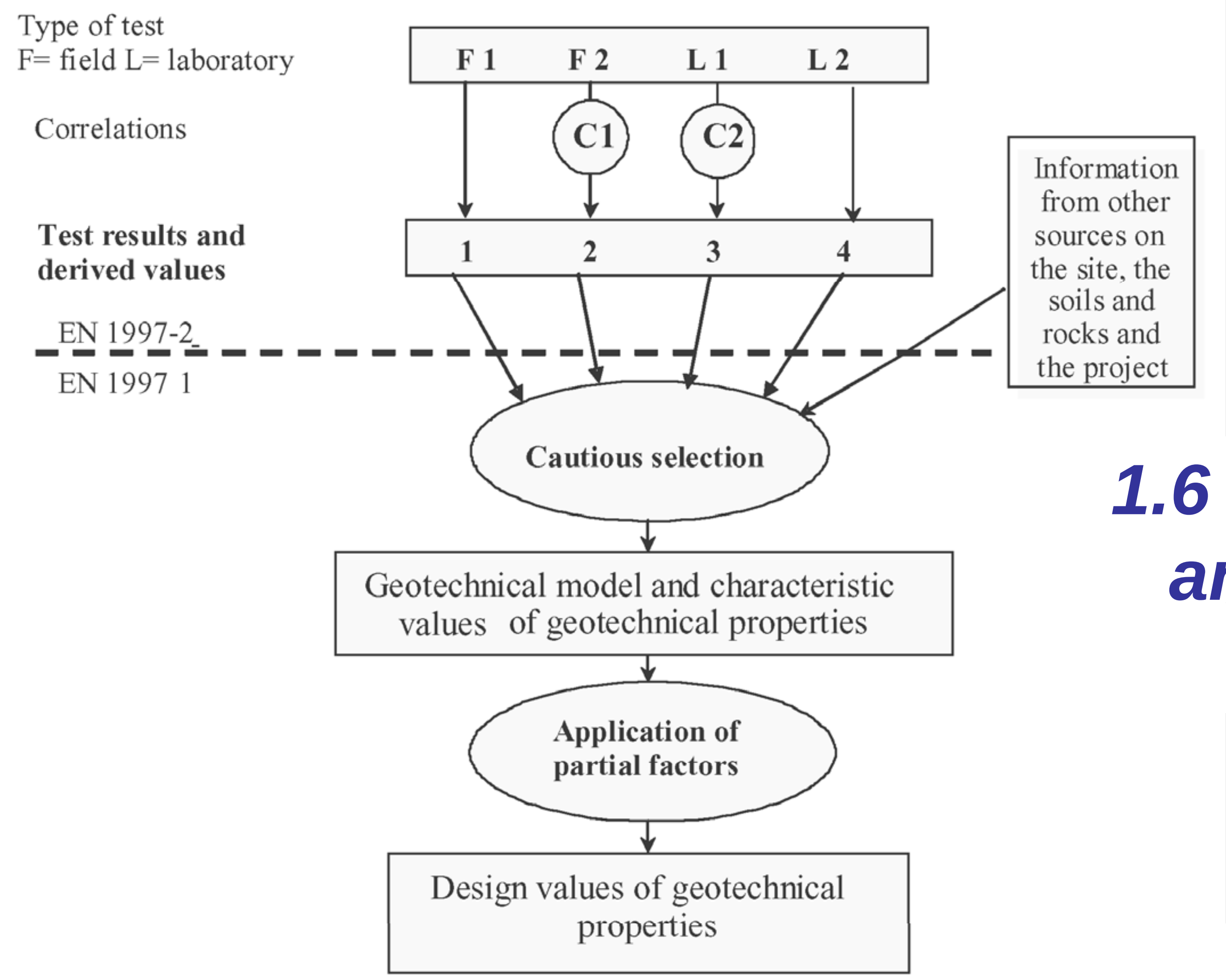
6.3 Evaluation of geotechnical information

(1)P The evaluation of the geotechnical information shall be documented and include, if appropriate:

- the results and a review of the field investigations, laboratory tests and all other information;
- a description of the geometry of the strata;
- detailed descriptions of all strata including their physical properties and their deformation and strength characteristics;
- comments on irregularities such as cavities.

6.4 Establishment of derived values

(1)P If correlations have been used to derive geotechnical parameters or coefficients, the correlations and their applicability shall be documented.



1.6 Test results and derived values

EC 7-1 – Characteristic values

2.4.5.2 Characteristic values of geotechnical parameters

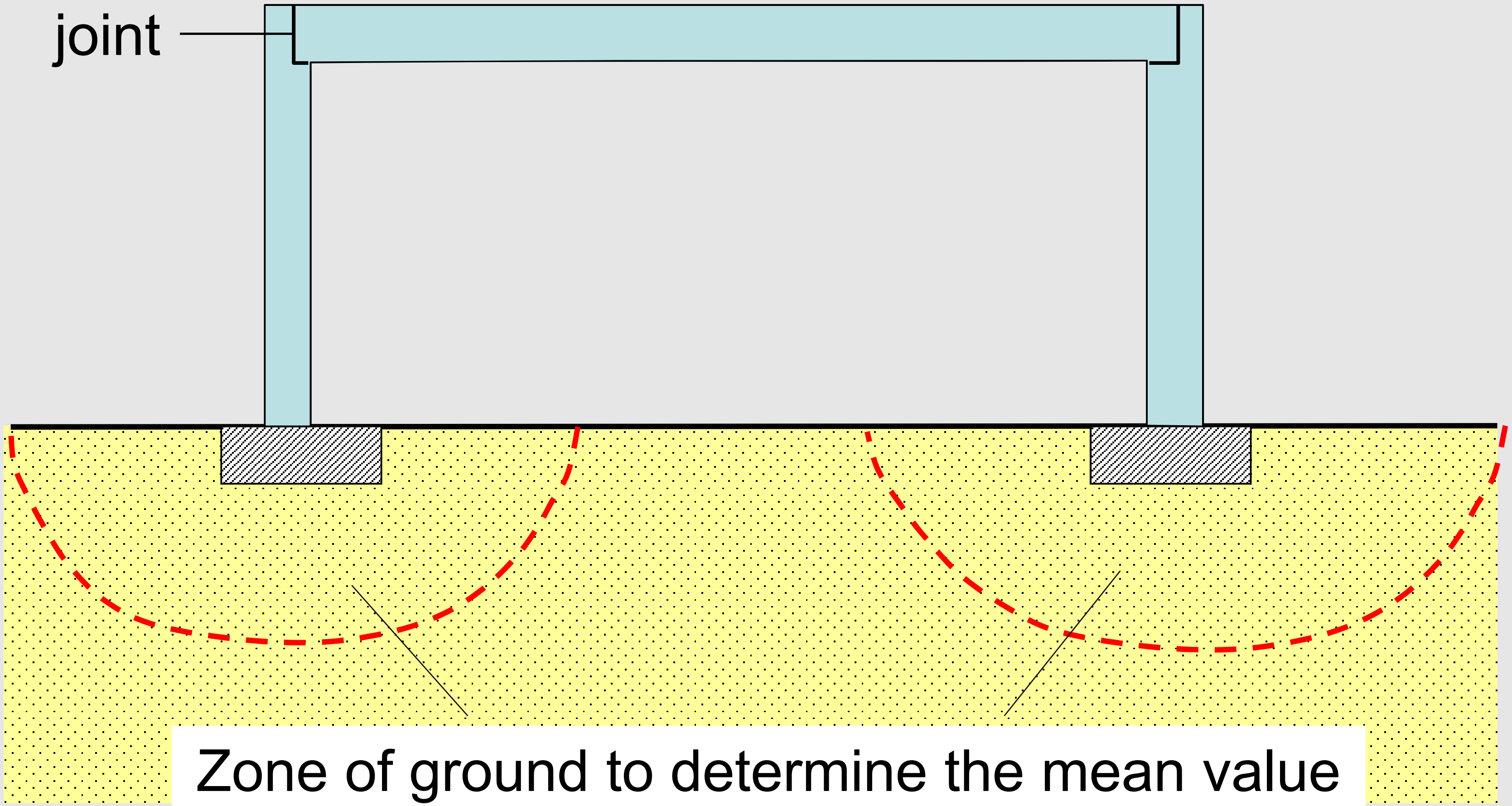
(1)P The selection of characteristic values for geotechnical parameters shall be based on results and derived values from laboratory and field tests, **complemented** by well-established experience.

(2)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

2.4.5.2 Characteristic values of geotechnical parameters

(9) When selecting the zone of ground governing the behaviour of a geotechnical structure at a limit state, it should be considered that this limit state may depend on the behaviour of the supported structure. For instance, when considering a bearing resistance ultimate limit state for a building resting on several footings, the governing parameter should be the mean strength over each individual zone of ground under a footing, if the building is unable to resist a local failure. If, however, the building is stiff and strong enough, the governing parameter should be the mean of these mean values over the entire zone or part of the zone of ground under the building.

Individual footings

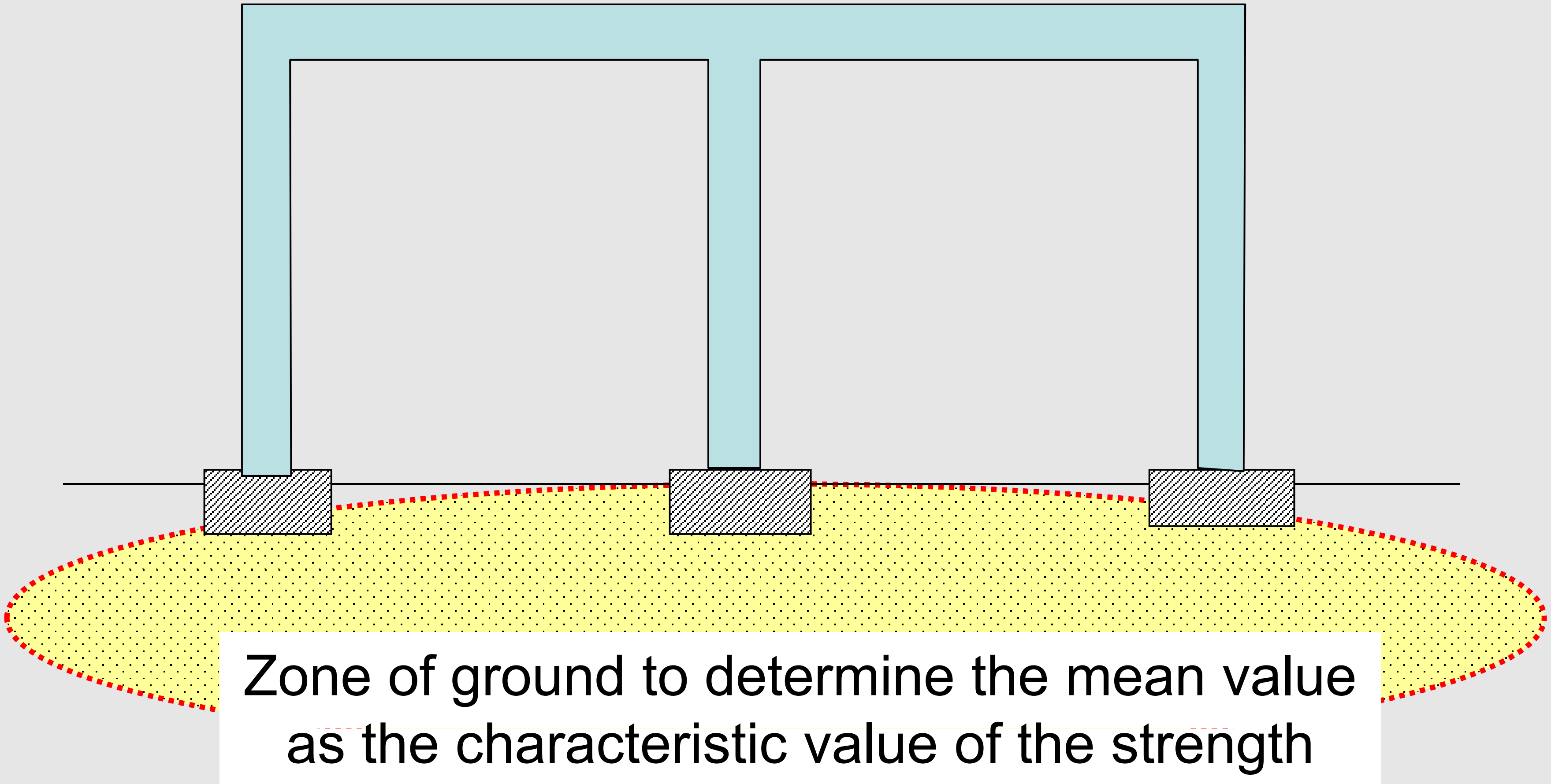


Zone of ground to determine the mean value as the characteristic value of the strength

2.4.5.2 Characteristic values of geotechnical parameters

(9) When selecting the zone of ground governing the behaviour of a geotechnical structure at a limit state, it should be considered that this limit state may depend on the behaviour of the supported structure. For instance, when considering a bearing resistance ultimate limit state for a building resting on several footings, the governing parameter should be the mean strength over each individual zone of ground under a footing, if the building is unable to resist a local failure. If, however, the building is stiff and strong enough, the governing parameter should be the mean of these mean values over the entire zone or part of the zone of ground under the building.

Influence of the stiffness of the structure

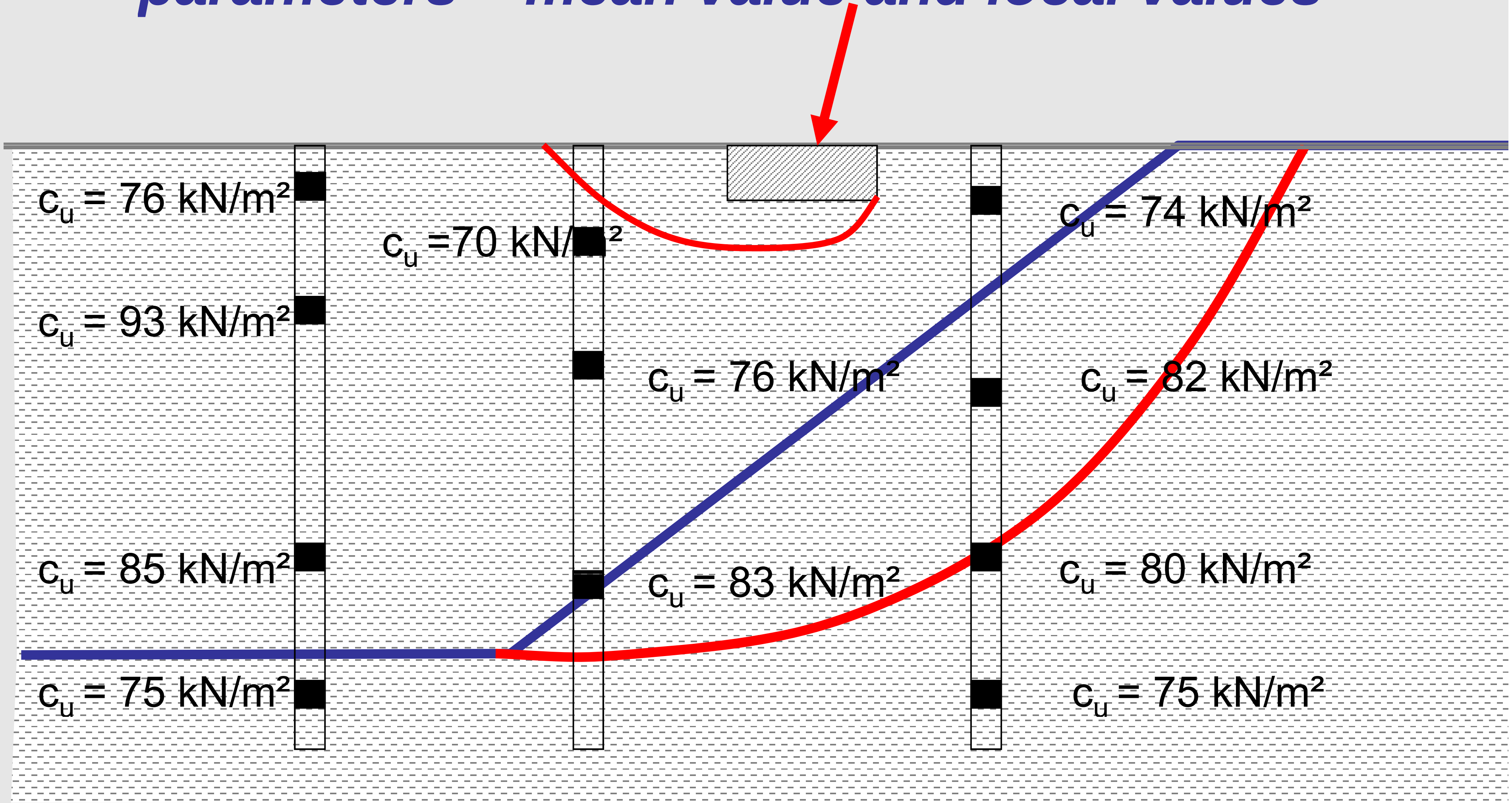


2.4.5.2 Characteristic values of geotechnical parameters

(11) 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%.

NOTE In this respect, a cautious estimate of the mean value is a selection of the mean value of the limited set of geotechnical parameter values, with a confidence level of 95%; where local failure is concerned, a cautious estimate of the low value is a 5% fractile.

Examples of the selection of characteristic ground parameters – mean value and local values



Statistical evaluation of test results

Charakteristiv value X_k of a normally distributed sample of test results:

$$X_k = X_m (1 - k_n \cdot V_x)$$

Where

X_m arithmetic mean value of the test results;

V_x coefficient of variation

k_n a statistical coefficient depending on the number **n** of test results, the selected probability for the occurence of $\mathbf{X_k}$ and whether the coefficient of variation $\mathbf{V_x}$ is known or not..

Statistical evaluation of test results

Schneider (1999) :

$$\mathbf{X_k = X_m - 0.5 \cdot s_x}$$

s_x: Standarddeviationof the sample

Statistical evaluation of test results

11 test results

Mean value: $c_{u,m}$ = 79 kN/m²

Coefficient of variation V_{cu} = 0,08

	Equation	k_n	$c_{u,k}$ kN/m²
Global characte-ristic value	$c_{u,m,k} = c_{u,m} (1 - k_{n,m} V_{cu})$	0,55	**75,5**
	$c_{u,m,k} = c_{u,m} - 0.5 \cdot s_{cu}$	-	**75,8**
Local charasteric value	$c_{u,l,k} = c_{u,m} (1 - k_{n,l} V_{cu})$	1,89	**67,2**

European Commission

Geotechnical design with worked examples

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