Geotechnical Eurocodes

OBJECTIVES

- To describe the Eurocodes relevant to geotechnical design.
- To emphasise the responsibilities placed on the geotechnical engineer and the need for close liaison with other disciplines.
- The designer has a mandatory obligation to prepare a Geotechnical Design Report. This includes the Ground Investigation Report. Input into the geotechnical aspects affecting the construction phase are also required.
- To outline the general approach to risks in geotechnical engineering.
- To introduce the concept of limit states and methods of their verification.
- To describe the different types of actions and effects of actions.
- To explain the derivation of the design resistances, the design approach and the partial factors.
- To describe techniques for the determination of characteristic values of geotechnical parameters.

Relevant Eurocodes

The relevant Eurocodes for geotechnical design are described in Table 1. Other geotechnical Eurocodes are introduced elsewhere in the relevant chapters of ***Soil Mechanics: Principles and Practice***. For the latest information, please see http://eurocodes.jrc.ec.europa.eu/ © European Union, 1995–2017.

Personnel

Persons carrying out the design and choosing the relevant structural components such as type of pile, anchorage and geotextile are required to be appropriately qualified and experienced in geotechnical engineering.

Traditionally, a structural engineer has provided the geotechnical engineer with the actions (loads) applied by a structure to the ground such as for the design of a foundation. With the limit state approach, consideration of the actions must be made simultaneously with consideration of the geotechnical resistances. This will require adequate (generally more) communication between the disciplines.

Equally, engineers who are not specialised in geotechnical engineering should be wary of planning and conducting geotechnical investigations and designs given the requirements of appropriate qualifications and experience and the range of geotechnical design situations to consider.

Geotechnical Design Report

This is a mandatory requirement formalising the assumptions made, data used, methods of calculation and the results of the verification of the limit states. It should describe the ground model and the effects on and of the proposed construction. It should justify the assumptions and design calculations, make recommendations and identify risks.

Table 1 *Relevant Eurocodes for geotechnical design*

Standard and title	Description
BS EN 1990:2002 Eurocode – Basis of structural design NA to BS EN 1990:2002	These describe the terms and definitions, the principles of limit state design, the various actions and the verification of the limit state by the partial factor method.
BS EN 1991 Eurocode 1 – Actions on structures	In the UK, the structural British Standards, BS 5400 and BS 6399, are superseded by this Eurocode. The geotechnical engineer is required to understand how the actions are derived, usually by a structural engineer, so that the appropriate limit states and partial factors are applied.
BS EN 1997-1:2004 Eurocode 7: Geotechnical design – Part 1: General rules	This describes the basis of geotechnical design and the derivation of geotechnical parameters. The supervision of construction, the monitoring of the performance of the structure and its subsequent maintenance are now requirements not always previously addressed by the designer. There are sections on various aspects of geotechnical design including spread and pile foundations, anchorages, retaining structures, embankments, hydraulic failure and overall stability. All aspects of the geotechnical design are to be incorporated into a Geotechnical Design Report.
BS EN 1997-2:2007 Eurocode 7: Geotechnical design – Part 2: Geotechnical investigation and testing	This describes the planning of ground investigations, soil and rock sampling, groundwater measurements, field and laboratory tests in soil and rock, and the requirements of the Ground Investigation Report. BS 5930:1999, the UK code of practice for site investigations is to be a withdrawn/revised to remove conflicts. For laboratory testing, in the UK, BS 1377:1990 will remain the preferred standard.
NA to BS EN 1997-1:2004 UK National Annex to Eurocode 7: Geotechnical design – Part 1: General rules	Each country has its own National Annex for each Eurocode but they may only contain information on those parameters which are left open in the Eurocodes for national choice, known as Nationally Determined Parameters. In this book, the UK National Annex (NA) is referred to.

A Ground Investigation Report must be included as part of the Geotechnical Design Report. This must include the entire factual field and laboratory investigations and a full geotechnical evaluation of the project, see Chapter 14 in ***Soil Mechanics: Principles and Practice*** for details.

The designer is no longer allowed to be divorced from the construction phase. A plan of supervision, monitoring and checking during construction must be prepared and provided to the owner/client. The checks, once completed, must be recorded in an addendum to the Geotechnical Design Report.

Geotechnical risk

It is generally recognised that most of the risks on construction projects lie within the ground conditions. These risks must be identified and managed, not ignored.

EC7 requires that structures are classified into Geotechnical Categories 1, 2 or 3, as detailed in Table 2. For each of these categories, a plan of supervision and a monitoring programme is required in the Geotechnical Design Report. For categories 2 and 3 the report may state the sequence of construction envisaged in the design or it may allow this sequence to be decided by the contractor.

Table 2 *Geotechnical categories*

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Geotechnical Category	Description
1	Small and relatively simple structures for which it is possible to ensure that the fundamental requirements will be satisfied on the basis of experience and qualitative geotechnical investigations with negligible risk For example, straightforward ground conditions, local experience, no excavation below the water table.
2	Conventional types of structure and foundation No difficult soil or loading conditions Quantitative geotechnical data and analyses required Routine procedures for field and laboratory testing No exceptional risk For example, spread, raft and pile foundations, retaining walls, bridge piers and abutments, embankments, ground anchors, tunnels and excavations.
3	Those structures not in categories 1 or 2 Very large or unusual structures Difficult ground or loading conditions Abnormal risks Highly seismic areas Areas of ground instability. For example, mining, solution, collapsible soils, frost action.

Different regimes for each category are adopted for inspection of the construction works, quality control, checking the exposed ground and groundwater conditions and performance of the works in relation to the design assumptions.

For Category 1 structures, the minimum requirements for ground investigations, design procedures, construction control and performance evaluation may be satisfied by experience, simple inspections and qualitative geotechnical investigations, provided this is agreed with the client.

For categories 2 and 3, measurements of the ground properties should be conducted and additional ground investigations may be needed. Monitoring of performance in relation to the sequence of construction is required with measurements of displacements and appropriate ongoing analyses.

Geotechnical Risk Register

In response to cost overruns on highway projects in the UK, the Highways Agency introduced a standard, HD 22/02 Managing Geotechnical Risk (DMRB, 2002), now superseded by HD 22/08, available as a pdf at http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol4/section1/hd2208.pdf. The main requirements of this standard are the provision of Geotechnical Certification and risk reports prepared by the designer. The risks are assessed at all stages of a project from initial inception to post-construction feedback.

To formalise the process, a Geotechnical Risk Register is produced at project inception and reports are prepared at different stages. These documents remain live throughout the design and construction processes.

In the Risk Register, hazards/risks are identified, their site-specific causes are recorded and the consequences to the project if they occur are assessed in terms of health and safety, cost, the environment and the construction programme.

A risk rating can be applied based on the probability of occurrence and the impact on the project. Risks with low ratings may be accepted or monitored during construction while risks with high ratings should be avoided by modified designs and/or construction procedures.

Durability

Deterioration of materials buried in the ground can affect their long-term properties. These may include acid or sulfate attack of concrete, corrosion of steel, fungal, bacterial or microbial action on timber and degradation of geosynthetic fabrics.

This may result in reduction of the effective geometrical dimensions; for example steel sheet piling in contact with sea water is designed with a greater thickness to allow for a sacrificial layer to corrosion.

Reduction of the material strength will affect the resisting capacity of the materials. For example, the strength of geogrids used to reinforce soil walls and embankments is reduced to allow for long-term deterioration.

Geometrical data

A foundation may be designed as 2.5m square, say, supporting a central column, but it may not be constructed to these dimensions exactly due to the inaccuracies of construction. In EC7 the effects of imperfections in the geometrical dimensions of a structural member are considered, and are related to the tolerances in construction, for example, the size, shape and location of a spread foundation.

Design values of geometrical data, a_d, may be represented by nominal values a_{nom}:

$$a_d = a_{nom} \tag{1}$$

Where the effects of deviations in geometrical data may be significant the design values are defined as

$$a_d = a_{nom} \pm \Delta a \tag{2}$$

Δa takes account of unfavourable imperfections and the cumulative effect of simultaneous intolerances. For example, a spread foundation is made smaller than designed and set out in a position such that the supported column is no longer central but produces eccentric loading. Does the contractor remove the offending foundation or can the designer verify that the limit state is still not exceeded?

The sensitivity of the design should also be checked for the variability of geometrical data that may be anticipated in the ground model, such as the levels of the interfaces between strata and groundwater levels. In addition, there may be changes to the ground surface level during construction, such as for temporary works and the depths of excavations (over-excavation). These should be included in the design.

It should be appreciated that the accuracy of the geotechnical geometrical data used in a design is only as good as the quality and adequacy of the ground investigations.

Limit states – Ultimate

It is necessary to distinguish between ultimate limit states and serviceability limit states:

Ultimate limit states are defined as states associated with collapse or with other similar forms of structural failure and concern the safety of people and the structure.

These are defined as states beyond which the structure no longer satisfies the design performance requirements. This could represent a range of limits from:

- Collapse of the whole or part of a structure due to excessive movement such as subsidence, settlement, heave, seepage force, wall deflection.
- Collapse of the whole or part of a structure due to ground failure by exceeding the bearing resistance, sliding resistance or overall instability, such as in a slope, embankment or retaining wall.

EC7 recognises five ultimate limit states:

- EQU – loss of equilibrium of the structure or the ground, considered as a rigid body, in which the strengths of structural materials and the ground are insignificant in providing resistance. This limit state is mostly relevant to structural design.
- STR – internal failure or excessive deformation of the structure or structural elements, including, for example, spread foundations, piles or basement walls, in which the strength of structural materials is significant in providing resistance.
- GEO – failure or excessive deformation of the ground, in which the strength of soil or rock is significant in providing resistance.
- UPL – loss of equilibrium of the structure or the ground due to uplift by water pressure (buoyancy) or other vertical actions.
- HYD – hydraulic heave, internal erosion and piping in the ground caused by hydraulic gradients.

Ultimate limit state design is then carried out by setting up models for the structure with load cases in various design situations, setting up ground models with design values of geometrical data and geotechnical parameters, calculation models to determine the design ground resistances and verifying that the effect of the actions or load cases does not exceed the ground resistance.

Limit states – Serviceability

Serviceability limit states correspond to conditions beyond which specified service requirements for a structure or structural element are no longer met and concern the comfort of people, the functioning of the structure and its appearance.

These are defined as states beyond which the structure no longer satisfies the design performance requirements. This could represent a range of limits from:

- Cracking which gives an unsightly appearance.
- Unacceptable vibrations.
- Distortion or deflection that leads to loss of weather-tightness or impaired durability or loss of function.

Serviceability limit states can be a little more flexible in that they depend on subjective views regarding people's perceptions of function, appearance and comfort. Avoiding these limit states in all events may lead to poor economy of design so although performance criteria must be deemed unacceptable possibilities, they should not be unnecessarily severe.

The Eurocodes give guidance on the choice of serviceability criteria but these should be specified for each project and agreed with the client.

Verification of limit states

The approach in limit state design is to verify that:

- For ultimate limit states, the effects of the design actions (E_d) do not exceed the design resistance (R_d) of the structure or ground.

$$E_d \leq R_d \qquad (3)$$

- For serviceability limit states, the effects of the design actions (E_d) do not exceed the performance criteria (C_d) of the structure.

$$E_d \leq C_d \qquad (4)$$

R_d is the design ground resistance available to prevent the occurrence of the ultimate limit state and C_d is the limiting design value of the relevant serviceability criterion.

Different design actions are determined for these two limit states. The effect of the design actions attempting to exceed the ultimate limit state would include force, stress, strain, moment and for serviceability limit states this could include settlement, deflection, tilt and rotation.

Limit states should be verified by one or a combination of:

- Adoption of prescriptive measures.
- Experimental models and load tests.
- An observational method.
- Use of calculation methods.

Design by prescriptive measures

These measures involve conventional and generally conservative design rules used where calculation methods are not available or are not necessary. Although not stated they would apply to Geotechnical Category 1 structures. The UK National Annex requires that the use of prescriptive measures should be agreed with the client.

Design by experimental models and load tests

These could include loading tests on shallow spread foundations, trial embankments, piles and anchorages. From the load-deformation or load-pore pressure relationships geotechnical parameters can be back-analysed and the monitored performance used to justify the full-scale design.

The advantage is that a large mass of soil in its *in situ* stress state undergoes testing. For small-scale model tests scale effects must be considered and where the test duration is shorter than the long-term behaviour of the structure, time effects such as pore pressure dissipation and creep should be allowed for.

Observational method

This does not mean design by observation but where reliable prediction of the geotechnical behaviour would be difficult or uncertain, the behaviour of the structure is monitored during construction and thereafter.

The results from various surveying and geotechnical instruments would be recorded and analysed in order to review and adjust, if necessary, the design of the structure.

The 'design' must include the determination of the acceptable limits of likely behaviour, for example the range of deflections of a propped embedded retaining wall. This would be checked against the actual behaviour obtained from a planned monitoring programme.

Contingencies for unacceptable behaviour must be predetermined. EC7 makes it clear that during construction, the monitoring shall be carried out as planned; it shall be assessed and appropriate decisions made. This may seem obvious but complacency can lead to dire consequences.

The method is particularly useful where ground–structure interaction cannot readily be determined, such as for excavations for basements. Here the different stiffnesses of the structural elements, the variable stiffness of the ground and the state of stress existing in the ground will affect the magnitude and distribution of earth pressures and hence the internal structural forces, bending moments and deflections.

Design by calculation

This is the process that most designers would expect to undertake in their working lives. It is the reason why students study the analytical parts of the subjects in order to become designers. However, in geotechnical engineering, information about the ground has to be sought out by ground investigations and there will always be uncertainties remaining.

The reliability of a design is only as good as the quality and quantity of information obtained for each site. To reinforce this plea for quality investigations the following is quoted from EC7:

> 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 requirements than is precision in the calculation models and partial factors.'**

Models and model factors

A calculation model may consist of an analytical model, a semi-empirical model or a numerical model and may include simplifications, but it must be either accurate or err on the side of safety. For this reason, the Eurocode introduces the concept of the 'model factor'.

$\gamma_{R;d}$ is the model factor associated with the design resistance, R_d, and $\gamma_{S;d}$ is the model factor associated with the design value of the effect of actions, E_d.

Model factors are applied to certain aspects of the design of pile foundations. They may be applied when an innovative method of analysis of a building or bridge is adopted or the reliability of the calculation method is uncertain.

For buildings designed with conventional calculation methods, it is assumed that the partial factors quoted in the Eurocodes include the model factors.

Actions

These are all of the factors that may attempt to exceed the limit state and include, with the appropriate symbol:

- Direct action (F) – a set of forces (loads) applied to the structure, such as column loads, struts, self-weight, earth pressures, water pressures, seepage forces, removal of load, excavation.
- Indirect action (F) – a set of imposed deformations or accelerations such as moisture variation (such as swell/shrinkage of expansive soils, effects of tree roots, vegetation), temperature changes (such as frost action, heated soils), uneven settlement (such as mining, tunnelling, slope creep, tilt, angular distortion), changes in soil composition (such as erosion, liquefaction, dispersion, solution, degradation, decomposition, self-weight compression).
- Permanent action (G) – action that does not vary with time and persists throughout the design life of the structure; for example self-weight of structures, anchorages, water.
- Variable action (Q) – action that varies with time, for example, imposed loads, storage contents, traffic, snow, wind, water. Also, combined variable actions should be considered.
- Effect of action (E) – the effect on the structural member and/or the ground from the applied actions, for example internal force, moment, stress, strain,

or on the whole structure, for example deflection, rotation.

- Accidental action (A) – this is an action of short duration but significant magnitude. It is unlikely to occur during the design life of the structure but would cause severe consequences unless appropriate measures were undertaken, for example impact of a vehicle on a bridge pier, explosions.
- Seismic action (A_E) – this is an action that arises due to earthquake ground motion.
- Geotechnical action – this is an action transmitted to the structure by the ground, fill material or groundwater. An example is earth pressure acting on a retaining wall.
- Fixed action – the position, magnitude and direction of the action are determined unambiguously.
- Free action – action that may have various spatial distributions, for example, traffic loading, impact loading.

Design situations and values of actions

Consideration of the 'design situation' should be made. These are mainly either persistent design situations, which refer to conditions of normal use, that is, long-term conditions, and transient design situations, which refer to temporary conditions such as during construction or repair, that is, short-term conditions. There are also accidental design situations and seismic design situations.

Characteristic and representative values of actions

The characteristic value of an action is its principal representative value. In general, therefore, the representative value of an action is given by

$$F_{rep} = F_k \qquad (5)$$

For permanent actions (G_k) this value is specified as:

- A mean value if the variability is small.
- An upper ($G_{k,sup}$) or lower ($G_{k,inf}$) value. This would refer to a statistical distribution if the variability is significant.
- A nominal value. This does not refer to a statistical distribution but would be determined from experience.

Variable actions (Q_k) are specified as either:

- An upper ($Q_{k,sup}$) or lower ($Q_{k,inf}$) value depending on whether the conditions are unfavourable or favourable, or
- As a nominal value, usually specified for a particular use, based on experience.

Variable actions may also be represented (Q_{rep}) as a:

- Combination value, given by $\psi_o Q_k$
- Frequent value, $\psi_1 Q_k$, or as
- Quasi-permanent value, $\psi_2 Q_k$

where values of the factors ψ are ≤ 1.

Design values of actions

The design value of an action is given by the general expression

$$F_d = \gamma_F \cdot F_{rep} \qquad (6)$$

where γ_F is the partial factor on actions.

Effects of actions E_d

The effects of actions could be in terms of internal force, stress, strain and moment for structural members and deflection and rotation for overall structural performance.

The design value of the effects of the actions, E_d, is the outcome of a verification procedure, such as that resulting from a calculation method, using the design geometrical data, a_d, and all of the actions (generally termed F_{rep}, both permanent and variable) multiplied by their respective partial factors, γ_F, combined with the design values of the geotechnical parameters (X_d).

When the partial factors are applied to the actions themselves, E_d can be expressed as

Design effect of actions = Effect of {factored representative actions; factored geotechnical parameters; geometrical data}, i.e.

$$E_d = E\{\gamma_{F,i} F_{rep,i}; X_k/\gamma_M; a_d\} \qquad (7)$$

where i is the number of actions, which may be greater than or equal to 1.

In some situations it is more realistic to apply the partial factors to the effects of the actions such as when earth or water pressures are determined, as earth pressures determined from factored geotechnical parameters may lead to unreasonable design values. Then

Design effect of actions = partial factor on effect of actions x Effect of {representative actions; factored geotechnical parameters; geometrical data}, i.e.

$$E_d = \gamma_E E\{F_{rep,i}; X_k/\gamma_M; a_d\} \quad (8)$$

Design resistances

These can be resistances determined from factored representative values of actions with partial factors applied to:

- The ground properties: $R_d = R\{\gamma_F F_{rep}; X_k/\gamma_M; a_d\}$ (9)
- Or resistances: $R_d = R\{\gamma_F F_{rep}; X_k; a_d\}/\gamma_R$ (10)
- Or both: $R_d = R\{\gamma_F F_{rep}; X_k/\gamma_M; a_d\}/\gamma_R$ (11)

Design approach and partial factors

Prior to the Eurocodes, the concept of limit state design and partial factors was common in structural design but not in geotechnical design. The traditional approach in geotechnical design has been to follow an analytical method incorporating reasonable estimates of the load and material parameters to obtain a derived ultimate value, such as bearing capacity.

This has then been reduced by an overall factor to provide for safety and stability. This ‘factor of safety’ has, without any in-depth consideration, also been deemed sufficient to allow for mobilisation of strength values, to provide for acceptable deformations and possibly even to cater for durability and deterioration.

Partial factors were introduced into Danish geotechnical practice by Brinch Hansen in 1953 and now form the basis for limit state design in EC7. Together with characteristic values they draw attention to the separate consideration of load conditions, material properties and design situations and provide a more robust approach compared to the global ‘factor of safety’ method.

A statistical approach to their application is illustrated in Figure 1, showing the relationship between design loads and design resistances for Combinations 1 and 2 of Design Approach 1.

Partial factors are chosen to ensure that the risk of failure of the foundation, and consequently the structure, is minimal so a combination of structural factors and geotechnical factors must be considered. These include:

- *Uncertainty of loading*
  With non-routine buildings and live loading, these effects are difficult to quantify, for example, wind, water forces, moving loads, dynamic forces.

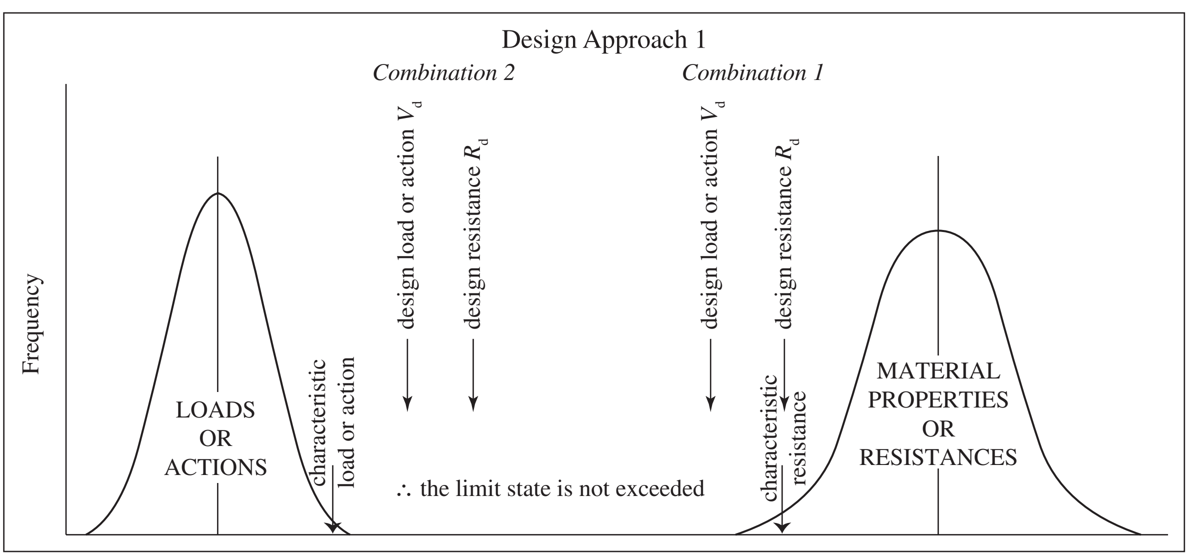

Figure 1 *Verification of the ultimate limit state*

Table 3 *Combinations of partial factors for Design Approach 1*

Source: based on information in http://eurocodes.jrc.ec.europa.eu/ © European Union, 1995–2017

The limit state of rupture or excessive deformation will not occur with either of these combinations	All design situations except axially loaded piles and anchors	Design situations for axially loaded piles and anchors
Combination 1	*A1* combined with *M1* combined with *R1*	*A1* combined with *M1* combined with *R1*
Combination 2	*A2* combined with *M2* combined with *R1*	*A2* combined with *M1* or *M2* combined with *R4*

- *Likelihood of maximum design load*
  For non-routine structures, it is likely that unfavourable variations of loading will occur, whereas routine buildings are often designed on nominal loading which is unlikely to occur.
- *Consequences of failure*
  The public will expect less risk to be taken with structures where failure could result in catastrophic consequences. More risk is taken with temporary works than permanent works.
- *Uncertainty of soil model*
  Geological variations, inaccuracy of strength values, water table fluctuations, mode of failure and limitations of the analytical method all provide uncertainty.
- *Extent of investigation*
  Sufficient depth of ground must be investigated to assess the layering of deposits, the uniformity of the ground conditions and a sufficient number of tests should be carried out to enable a reasonable choice of parameters.

The more extensive the site investigation, the more confidence there will be in the choice of the soil model and geotechnical parameters.

For the verification of the serviceability limit state, the partial factor applied to the permanent and variable actions and to the ground properties is unity.

EC7 permits the adoption of three Design Approaches, each one determined by different considerations of the actions (*A*), material properties (*M*) and resistances (*R*).

The UK National Annex requires that Design Approach 1 is adopted. This provides the partial factors on the actions, material properties and resistances for two combinations, 1 and 2. These combinations are detailed in Table 3. The values of the partial factors for Design Approach 1, combinations 1 and 2, are given in the UK National Annex.

Characteristic values of geotechnical parameters

The assessment of characteristic values of geotechnical parameters causes the geotechnical engineer the biggest headache. It is not easy to provide a definition of this value. EC7 requires that:

> 2.4.5.2(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.'**

Other terms that appear in the literature include:

- Moderately conservative value.
- Best estimate of the field value.
- More adverse than the most likely.
- Pessimistic estimate.
- Worst credible.
- Midway between expected and worst credible.

You will by now have realised that selecting soil parameters for design purposes is the most difficult yet most important task of the geotechnical engineer. Unfortunately, there are no clear guidelines that can be offered to address this problem. A useful discussion on this subject is given in Simpson and Driscoll, 1998.

Depending on its effect in the calculation, a characteristic value may be an upper or a lower value. These are described as higher or lower than the most probable value, respectively. EC7 requires that for each calculation, the most unfavourable combination of lower and upper values of independent parameters is used.

For example, lower values of density would be used where the soil acts favourably in support of the structure, such as passive pressure in front of a retaining wall. Upper values of density are used where the soil applies load unfavourably to the structure, such as active pressure behind a wall.

The properties of soils can be determined from:

- Test results, field and/or laboratory.
- Direct determinations such as weight density, γ, from triaxial specimens.
- Indirect determinations from correlations, either theoretical or empirical, such as s_u from SPT N.

However, these properties can vary spatially (across a site), vertically (with depth) and even for a homogeneous soil statistical variation arises due to the vagaries of obtaining values of the soil properties from field or laboratory tests on selected samples.

Selection of the characteristic value from the soil properties must take account of:

- Geological and other background information.
- Data from previous projects.
- The extent of the ground investigation, number of boreholes, samples, *in situ* and laboratory tests.
- The variability of the soil property values *in situ*, both with depth and spatially, and statistically.
- The extent of the zone of ground affected by the structure.
- The presence of weak zones and the ability for stress transfer to stronger zones either by local soil yielding or by structural interaction.

There may be differences between the soil property values and the parameter chosen due to different time effects, scale effects, mass fabric features and strain compatibility effects. The results of a ground investigation should not be considered in isolation, valuable input may be obtained from relevant published data or local experience.

Consideration should also be given at the design stage to changes that can be caused by construction activities including soil disturbance, swelling, shrinkage, weather deterioration and poor workmanship.

For example, the appropriate modulus value for a soil retained by a flexible wall will depend on the amount of deflection permitted during construction. At the design stage, it may be assumed as a small strain value but if large deflections are permitted, a lower soil modulus will be available.

The accuracy adopted in calculation methods should be tempered in the light of the above and output values obtained for, say, settlements or bearing capacities should be rounded up or down and reported in approximate terms.

We should encourage engineers from other disciplines to be more sympathetic to the difficulties faced by the geotechnical engineer so they could accept some of the uncertainties inherent in the ground. Unfortunately all too often we are expected to provide accurate answers to problems where the ground conditions have been poorly investigated.

Determination of characteristic values – *in situ*

In EN 1990:2002 the choice of a characteristic value for both loads and soil parameters is directed towards a statistical approach and EC7 allows for these methods to be considered for geotechnical parameters. The characteristic value may be derived based on the fractiles of the statistical distribution, Table 4.

This approach is appropriate with structural materials such as steel and concrete since their properties can be specified and their manufacture controlled before incorporation into the works to ensure compliance.

Table 4 *Statistical approach to characteristic values*
Source: based on information in http://eurocodes.jrc.ec.europa.eu/ © European Union, 1995–2017

Design situation is unfavourable with a	Use for the characteristic value
low value of the material property	5% fractile
high value of the material property	95% fractile

Take, for example, one cubic metre of concrete. Nearly 300 standard cube specimens could be prepared and tested to give a representative series of data for statistical analysis and to give confidence in the value of the characteristic strength derived. Providing the ingredients and their proportions are maintained and the placement and construction controlled, the structural engineer will have confidence in the properties of the concrete incorporated into the structure.

Then consider one cubic metre of soil in the ground. Up to 500 undisturbed triaxial specimens could be prepared and tested to give a representative series of data for statistical analysis and give confidence in the characteristic value of this cubic metre of soil.

However, this would be a laboratory derived result probably requiring adjustment for *in situ* mass effects such as fissures, differences in the field and laboratory behaviour such as plane strain and triaxial conditions, differences in stress applications and stress effects produced by the curvature of the failure envelope, scale effects, time effects and temperature effects. This is just for one cubic metre of soil. Note also that methods for such adjustments are not readily available.

In the geological context the ground model can vary dramatically due to stratification, weathering and stress history. This will produce significant variations with depth and across a site so that in effect many cubic metres of soil would have to be sampled and tested. In ground investigations, the ground is sampled and tested relatively infrequently so a limited amount of information is obtained.

Thus statistical approaches to characteristic values of soil properties for a whole site are fraught with difficulties.

Determination of characteristic values – *engineered fill*

For a man-made structure using an engineered fill, such as in an earth dam, where the material properties can be specified, then providing the soil material type is constant, its remoulded properties are known and monitored throughout construction, and the placement and construction are controlled, the geotechnical engineer will have more confidence in the properties of the soils incorporated into the structure.

Each soil will have a characteristic property value, say strength or compressibility, and, by definition, the geotechnical engineer will accept that no more than 5% of the soils incorporated may not provide the characteristic value.

For earth structures it is not common for the designer to specify particular materials, rather the materials sourced by the contractor (for economic reasons) must meet the minimum soil property values adopted by the designer. The designer must be prepared to reassess the design if the contractor proposes an economic alternative material.

SUMMARY

The Eurocodes relevant to geotechnical design are outlined.

The requirements of the personnel conducting geotechnical design are formalised together with the requirement of a Geotechnical Design Report. This report must include and justify the assumptions, data, calculations and limit state verifications.

The report must also include a plan of supervision, monitoring and checking during construction.

The risks associated with the ground conditions need to be recognised in relation to the Geotechnical Category of the project with appropriate performance monitoring.

The preparation of a Geotechnical Risk Register is introduced as a tool to minimise the consequences to a project, including health and safety, the environment, cost and programme overruns.

Aspects of durability and construction tolerances are to be considered at the design stage.

The ultimate limit state and the serviceability limit state are described with the means of verification, including design by prescriptive measures, experimental models and load tests and calculation methods and, where appropriate, the adoption of the observational method.

The various actions, effects of actions, resistances and partial factors are outlined. The design approach using characteristic values of geotechnical parameters and partial factors is described.

Characteristic values of geotechnical parameters are discussed.