**TC250/SC7/EG13: Rock mechanics**

**(draft) Interim Report** **2014**

# General commentary

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# Appendix A: clause-by-clause commentary

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# Appendix B: papers by members of EG13

EG13 papers prepared for the Workshop “Applicability and application of Eurocode 7 to rock engineering design”, Eurock 2014, Vigo, Spain

See separate document

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**General Commentary**

It is a general view of rock engineers that EN1997‑1:2004 is difficult, and in some circumstances impossible, to apply to rock engineering design and construction. However, geotechnical engineers require clear rules and guidelines to follow when undertaking rock engineering design, and as EN1997 has the status of a Reference Design Code within Europe, they are attempting to use it.

Through the organisation of Workshops, authorship of conference papers and participation in professional meetings, the members of EG13 have actively been discussing the applicability of EN1997‑1:2004 to rock engineering design. This work has led EG13 to identify a number of suggestions for improvements that will facilitate the application of the future EN1997 to rock engineering design. The principal results of the work to date of EG13 are summarised here.

1. The proposed new structure of EN1997, namely a division into the three parts of General Rules, Ground Investigation, and Geotechnical Constructions, appears to be very suitable for encapsulating the guidance needed to allow high quality rock engineering design.

2. EN1997 is intended to be used in conjunction with EN1990. However, there are fundamental differences between industrially produced materials like concrete and steel as used in structural engineering, and natural geo‑materials like soil and rock. These differences imply that different approaches have to be applied to describe the uncertainties in material properties and the interpretation of the concept of probability.

Uncertainties in soil and rock mechanics are more epistemic than aleatory in their nature. There are also the problems introduced by scale dependency and space correlation of parameters describing both soil and rock material. The basic assumption in EN1997 that material properties – such as rock mass parameters – are aleatory in nature may therefore not always be valid. In those cases of design verified by calculations, these epistemic uncertainties have to be quantitatively evaluated. This suggests the need for the future General Rules to EN1997 to define and discuss the different type of uncertainties.

Every design situation is in principle unique. The probabilistic basis has accordingly to be changed from a frequentist to a Bayesian model, with the associated use of “Degree of Belief”. Again, this needs to be covered in a future General Rules to EN1997. However, it is recognised that the application of Bayesian statistics to limit state design is a young subject, and one in which much fundamental research remains to be undertaken.

It is a problem that frequentist and Bayesian statistics strictly cannot be applied to anything other than objectively measured quantitative phenomena, because this means that none of the subjective, qualitative assessments regularly made in rock mechanics are applicable in terms of EN1990.

EG13 wishes to discuss all these issues with SC7 in order to identify solutions that are acceptable to all parties.

3. A fundamental requirement of EN1997 is that for each geotechnical design situation it it necessary to verify that no relevant limit state is exceeded. The principles of this are given in EN1997‑1:2004 §2 Basis of geotechnical design. However, even if these principles are applicable to rock engineering design, a major revision will be necessary in the future EN1997 as this Section is currently written mainly from the perspective of a soil mechanics. Further examples of this bias towards soil mechanics are highlighted in the paragraphs below.

4. The design methods to verify the limit states are not fully compatible with the methods given in EN1990:2002 §3.5(4) and (5). This needs to be discussed and clarified.

5. In relation to legislation with requirements for safety, serviceability and durability, the concept of limit state design is understandable. However, many design situations in rock engineering customarily do not use calculations to verify the design and limit state. The future EN1997 should be written to recognise this, whilst attempting to give impetus to gradual improvement in terms of limit state principles to rock engineering design methodologies.

6. The definitions of Geotechnical Categories need to be revised in order to be applicable to recognised rock engineering design.

7. The ultimate limit state in rock engineering designs is often connected to several different failure modes, which in turn may to varying degrees be spatially repeated and correlated. Identification of the relevant failure modes therefore relies to a large degree on detailed knowledge of the rock mass structure. In some cases these failure modes are designed against through application of prescriptive measures, and in other cases verification by calculation is employed. This is the case for both local failure and total instability of rock slopes and tunnels. In general, application of probabilistic methods is too complicated for such types of multiple failure modes problem.

These issues need to be addressed in the future EN1997.

8. Verification of limit states by calculation may be carried out with partial factors. Unfortunately, this approach involves many difficulties for rock engineering design. For many problems in rock mechanics the partial factors either do not exist or are not calibrated for rock masses and discontinuities. In either case it may be difficult to obtain them, simply because, even assuming an aleatory model is applicable, such factors refer to a mathematical model that links resistance and effects of actions for a particular problem geometry. If the geometry or the relative influence of a parameter changes, the partial factors will change. Also, many problems in rock mechanics are of the form of rock-structure interactions, whereby the effect of an action increases the resistance. This phenomenon is normally ignored in structural engineering, but is of critical importance in geotechnical design. Unfortunately the partial factor method seems unsuitable for these interaction phenomena.

This problem of design situations and verification methods needs to be further discussed.

9. The derivation of characteristic values of soil and rock materials is much more complex than for man‑made engineering materials such as steel and concrete. The application of percentile values as EN1990:2002 suggests is neither meaningful nor theoretically correct. The nature of epistemic uncertainties in combination with small numbers of test results or empirical assessments complicates the derivation of these values.

It is recognised that EN1997‑1:2004 §2.4.5.2 allows for using the mean value as a characteristic value, or for values that are chosen as a cautious estimate. However, these non‑statistical approaches need to be better described and defined.

10. Non-linear stress-strain relations are common in rock mechanics, both for rock discontinuities and rock masses. Many of these relations are empirical, with the underlying properties often being estimated from subjective qualitative assessment.

Identification of robust procedures to estimate characteristic or representative values in such circumstances needs to be discussed.

11. Design by prescriptive measures is very common in rock engineering, but EN1997‑1:2004 offers inadequate coverage of this. Thus, this aspect of rock engineering design needs greater attention in the future EN1997.

If prescriptive measures in rock engineering are thought to include the application of rock mass classification schemes (and it is not certain that this is the case), then how this should be undertaken for structures in Geotechnical Categories 2 and 3 needs to be clarified. It is not clear what ‘verification by adoption’ means, particularly in the context of subjectively assessed rock mass properties, and hence whether this particular principle is applicable. Again, this needs to be clarified.

12. Verification by applying Observational Methods (OM) is very common in rock engineering design. EN1990 introduces ‘design by testing’, but although this superficially has some similarity with OM, it is not applicable to rock engineering. In the current EN1997 the distinction between OM and monitoring is unclear, and the section describing the OM is unsuitable for application to rock engineering.

In the future EN1997, OM needs further elaboration in order to better fit the approach actually used in rock engineering practice. In particular, the issue of verification of limit states in the context of the OM needs to be properly clarified.

13. EN1997‑1:2004 §3 Geotechnical data covers investigation of both soil and rock material. In the future EN1997, it is thought that this Section would be more readily applicable if it were divided into a general part, and parts for each of soil and rock. However, it is essential that guidance be given to transitional materials, i.e. those circumstances where the distinction between soil and rock is not clear (i.e. weathered materials, soft rocks/stiff soils, ground containing a combination of soil and rock). The description and characterisation of intact rock, rock discontinuity and rock masses, together with heterogeneity, anisotropy and scale dependency needs to be further elaborated.

14. EN1997‑1:2004 §4 Supervision of construction, monitoring and maintenance is of critical importance to rock engineering, as these issues are related to the method to verify the design, the construction method to be adopted and the type of construction contract.

In the future EN1997 proper recognition needs to given to the difficulty of excavating rock to a design profile, and of the potential for material properties to be dramatically changed by the excavation process (i.e. blast damage). The section should be rewritten to be more clearly connected to general aspects and issues related to both design verification and construction method.

15. EN1997‑1:2004 §6 to §12 describe specific engineering applications. Very few rock engineering aspects are included within these. EN1997‑1:2004 §6.7 Foundations on rock, and EN1997‑1:2004 §11.5.2 Slopes and Cuts in rock masses, are two very short sections related to rock mechanics and rock engineering issues, but neither is sufficiently comprehensive with regard to geotechnical aspects and applications. Rock anchors, rock bolts and dowels are commonly used in rock engineering practice, but are not treated within EN1997.

A large part of rock engineering design carried out today is associated with the design of underground openings and tunnels. We consider that the design of rock tunnels which are either naturally stable or are stabilised by rock support and reinforcement can be separated from the design of structures such as cut‑and‑cover tunnels. This issue should be addressed and further developed in Phase 3 of the forthcoming maintenance process.

Finally, it is essential for rock engineering design that the application sections are in accordance with praxis and prudent contemporary rock engineering, and offer comprehensive cover age and treatment. Substantial further interaction with the rock mechanics and rock engineering communities is required to improve the sections dealing with rock engineering applications.

**Appendix A**

**Clause‑by‑Clause commentary on EN1997‑1:2004  
with respect to rock engineering design and construction**

This Appendix lists those elements of EN1997‑1:2004 that are considered to require improvement to more properly be suitable for rock engineering design. Elements not shown in this document are considered either to be unrelated to rock engineering or not to need any revision.

# 1 General

## 1.1 Scope

### 1.1.1 Scope of EN 1997

[1]

This first clause refers to structural reliability, as it is typically understood for structures built with construction materials, such as steel or concrete, which are continuous by nature. Their analysis therefore follows the rules of continuum mechanics. For soils such a design procedure can also be followed, as macroscopically they may be considered as continuous. However, rocks are not continuous materials. Joints and other fractures of geological origin tend to be ubiquitous features in a body of rock, and generally control the physical behaviour of the material. This is why customary structural reliability concepts may not be appropriate for rock engineering approaches.

[2]

Civil engineering works should be better defined. This is important in order to know which rock engineering constructions are included in the EN1997 scope.

[3]

Better examples are needed: the quoted thermal and acoustic could be SLS.

[4]

Reword to indicate that EN1991 is not an exhaustive list of actions.

EN1997 states that the potential failure mechanisms dictate the design approach, but depending on the nature of the mechanism forces can play the role of actions or resistances. Therefore, the identification of the failure mechanism (which is usually a straightforward matter in structural stability and soil mechanics) is of paramount importance in rock engineering terms.

[7]

Is this correct? Seismic load is currently not included in EN1997, but it should at least be mentioned as an action in Section 11.

### 1.1.2 Scope of EN 1997-1

[2]

Modify to account for new layout of EN1997.

The division in sections is not easy to understand. Creation of specific sections for different types of geotechnical constructions would be useful, such as: “foundations”, “retaining structures”, “slopes, cuttings and embankments”, “ground improvement”. A section on rock slope and rock cut stability, including rock‑fall protection, would be helpful, as well as a section on *in situ* stresses.

[3]

Modify to account for new layout of EN1997.

### 1.1.3 Further Parts of EN 1997

Add some notes about monitoring systems in general and in particularly in rock mechanics.

[1]

Modify to account for new layout of EN1997.

## 1.3 Assumptions

[2]

In the six bulleted sentence, it should be noted that in geotechnical engineering “construction materials” may be the ground (soil or rock mass), in which case they are not “specified”.

## 1.5 Definitions

### 1.5.2 Definitions specific for EN 1997-1

#### 1.5.2.1

Depending on the type of expected failure mechanism some forces can play the role of actions or resistances.

#### 1.5.2.3

Better to use “rock mass” than “rock”.

#### 1.5.2.4

1) The meaning of “structure” as defined in EC7 is too restrictive. The ground must be seen as part of the structure; not only “fill placed during execution”. Is ground included in the “organised combination of connected parts”? If this definition of “structure” implies that the ground is not part of the structure, this should be clearly stated.

2) However, the expression “rock mass structure” is also used in rock mechanics, and has a different meaning, related to the discontinuity pattern. This distinction should be made.

3) Some definition(s) concerning rock discontinuities, which are specific to EN1997, should be included.

#### 1.5.2.7

Depending on the type of expected failure mechanism some forces can play the role of actions or resistances.

## 1.6 Symbols

When defining parameters there is a bias in EN1997 towards soil mechanics (an example the fact that there are partial factor for soil parameters but not for rock masses or rock discontinuities). Typical rock parameters such as discontinuity roughness, strength or dilation are missing.

[2]

MPa (rock strength, in situ stress) and GPa (intact rock, discontinuity, rock mass stiffness) should be included.

# 2 Basis of geotechnical design

## 2.1 Design requirements

[2]

The definition of limit states is not straight forward in rock engineering. A comment on the topic will be most welcome.

Rock engineering structures may have an adverse effect on the surroundings (e.g. ground water, or induced vibrations during construction). Influence on the environment and not only influence of the environment should therefore be included.

[3]

Combined failure ought to be changed to “in both” since failure is not appropriate to all limit states.

[5]

In rock engineering a proper knowledge of discontinuities of all types (e.g. bedding planes, joints, faults) is essential for failure mechanism identification; previous experience may not be as relevant as for the case of soil related problems.

[8]P

The word calculations in the text should be changed to “limit states verifications”, since the paragraph is related to all the different methods of verification and not only calculations.

[9]

Should include works in rock masses.

[10]

Introduction of geotechnical categories is not mandatory, but is reasonable. However, the way the different geotechnical categories are defined is not sufficiently clear for rock engineering purposes.

[16]

This clause is ambiguous (e.g. pre-excavation water table, or a drawn-down water table). It also needs to recognise that rock excavation underwater may not need ‘local experience’.

[17]

‘Soil’ should be changed to ‘ground’ or ‘soil or rock mass’.

[18]

Many of the exemplar structures stated as complying with GC2 are common in rock engineering. This clause states that quantitative geotechnical data are normally required to verify the limit state is not exceeded, but parameters used in rock engineering design are qualitative. It is thus unclear if designs using qualitative assessments fulfil the requirements of this clause.

[19]

The given example of GC2 for rock structures is not adequate. All rock tunnels belongs to GC1 or GC2, except those which have exceptional risk such as high requirements of water tightness, large span, very shallow tunnels or in exceptionally poor rock.

Tunnels in non-fractured rock do not exist! Although rock tunnels are mentioned, are tunnels included in the scope of EN1997? Tunnels in soils are never mentioned. This should be clarified.

[20]

Similar to §2.1(18). Does this imply that structures in complex, fractured rock masses may use qualitative assessment to assess the occurrence of the limit state?

[21]

Do we need the examples? They add to confusion. The basic rules given in EC7 are inapplicable in geotechnical category 3. What may be needed are additional provisions and rules.

## 2.2 Design situations

[1]P

The term design situation is used in rock engineering in a broader sense than as given in EN1990:2002 §3.2. One is the impact of the rock structure on the environment.

[2]

“Ground on which the structure is located” should be “Ground on or in which the structure is located”; “are involved in any calculations model” ought to be “are involved in any method for verification of limit states”.

Replace “rock” by “rock mass”, include anisotropy of deformation and strength, add schistosity.

## 2.3 Durability

[2]

The rock mass may be soluble or erodible, so durability needs to be accounted for.

## 2.4 Geotechnical design by calculation

### 2.4.1 General

[1]P

This clause requires that geotechnical design by calculation should be based on the fundamentals set out in EN 1990, which is based on reliability analysis and probability theory. However, for rock mass parameters which are subjective and based on qualitative assessment, the design by calculation model in EN1990 may not be applicable.

[4]P

It is not only related to “if no reliable calculations model is available”, it is also related to the level of knowledge of ground conditions. In many cases it may be impossible to determine the conditions accurately enough in advance.

The use of ‘improbable’ implies the assessment of acceptability in terms of probability, which may not be appropriate for rock engineering where qualitative assessment precludes the use of probability theory

[11]

This may not be appropriate for rock engineering.

[12]

Replace “soil” with “ground”.

[13]

Rock support and reinforcement should be added.

[14]

Shotcrete (reinforced) and rock bolts are support and reinforcement systems that should be included here.

### 2.4.2 Actions

[2]P

This is impossible to understand.

[3]P

This can be difficult when the rock mass is sometimes the structure and sometimes an action on the structure.

[4]

The action is mainly related to soil mechanic issues. Delete the list or add the different ground behaviour types of rock to be considered. Consider adding pressures due to ground improvement measures such as grout injection or ground freezing.

[6]P

Replace “soil” with “ground”.

### 2.4.3 Ground properties

This clause should be amended to recognise that many parameters used in rock mechanics cannot be objectively measured through field or laboratory testing; the parameters are often qualitative, subjective estimates and determined directly for use in calculations. This clause could be expanded to provide some rationale in selecting and using such parameters in design.

[1]P

For the case of rock masses, properties should be not only based on laboratory and *in situ* testing, but also may be derived from a thorough characterisation of the rock mass founded on the recovery and interpretation of a good number of discontinuity data, level of fracturing, weathering degrees, geological features if observable, and the like.

[3]P

It is not clear if this quantification of properties refers to quantitative data, or can qualitative assessments of parameters values be made?

[4]

Include scale effects in rock masses. The part “rock structure (e.g. fissures, laminations, or large particles)”, should be replaced by “rock mass structure”, with a definition of rock mass structure given earlier in EN1997.

[6]P

Replace “rock” with “rock mass”.

Suggest adding that the type and degree of uncertainty in the value of a parameter shall be considered when establishing values of it.

### 2.4.4 Geometrical data

[1]P

Replace “levels of interfaces between strata” by “geometry of relevant interfaces between geotechnical units”.

### 2.4.5 Characteristic values

#### 2.4.5.1 Characteristic and representative values of actions

In general, this clause should be amended to consider that many parameters used in rock mechanics are qualitative, subjective estimates and determined directly for use in calculations. Therefore the terms ‘characteristic value’ and ‘cautious estimate of… probable’ values needs to be considered to make this clause more applicable to such situations.

#### 2.4.5.2 Characteristic values of geotechnical parameters

In rock engineering, many parameters cannot be determined using direct test methods; they are subjectively determined. This clause does not account for this.

In rock masses, the number and type of geotechnical parameters needed for the design will be dependent on the possible instability mechanisms, which should be identified prior to the analysis. This should be explained in this clause.

[1]P

The definition of ‘a cautious value’ needs either a more objective definition or improved guidance on its assessment.

[3]P

Reference to the strength parameters c' and tan(i') is inappropriate. In rock mechanics, strength parameters are required for intact rock, rock discontinuities and the rock mass. The particular parameters of c' and tan(i') are almost never applicable to these materials.

[4]P

Selection of characteristic values shall also consider degree and type of uncertainty.

[5]

EN1997 recommends using the most unfavourable combination of lower and upper values. This can be too extreme in rock mechanics, where large variations can be expected.

[7]

The definition of ‘a cautious value shall be a cautious estimate of this mean value’ needs more objective definition or guidance. This is particularly so when values are directly determined, in which case a mean does not exist.

[11]

Application of statistical methods implies that geomaterials display aleatory variability. This is not generally true in fractured rock masses. Some reservation regarding application of statistical methods in “geotechnical design by calculation” in rock masses should be included. EN1990 §4.2(5) says: “Where insufficient statistical data are available to establish the characteristic values of a material or product property, nominal values may be taken as the characteristic values...”. A nominal value is defined as: “value fixed on non-statistical bases, for instance on acquired experience or on physical conditions”. These definitions and statements show that statistical determination of characteristic values is the normal rule to be followed, but that other approaches are possible when insufficient data are available. A note on this should be added.

#### 2.4.5.3 Characteristic values of geometrical data

[1]P

This sentence is confusing, but seems to be primarily aimed at foundations and excavations in horizontal ground. It does not seem appropriate for, say, rock slopes. Should the geometry of rock mass structure belong in to this section?

### 2.4.6 Design values

#### 2.4.6.1 Design values of actions

As the main actions in geotechnical design are a function of the ground self weight, which also acts as a resisting action, perhaps a separation is required between ‘design values of external actions’ and ‘geotechnical actions’.

[2]P

With underground structures the mass of the ground seldom forms an action: the action is the deformation of the ground. It is therefore not correct to use this model for underground work.

[4]P

Persistent and transient situations refer to the load cases. Transient design situations are given at EN1990 3.2. However, an important transient situation in rock engineering is that of a rock structure being used in temporary circumstances – for example, an excavated rock slope before the final reinforcement and support is installed. Such circumstances need to be included in EN1997.

#### 2.4.6.2 Design values of geotechnical parameters

These partial factors clearly refer to soil parameters (e.g. undrained shear strength, effective cohesion and friction, unit weight) and not to intact rock, rock discontinuity or rock mass parameters. This needs to be updated for rock engineering parameters, or interim guidance given on use of the partial factors for parameters not included in Annex A.

[1]P

EN1990 §4.2(5) says: “Where insufficient statistical data are available ... design values of the property may be established directly”. This is generally the case with geotechnical property values, and so a note should be made to this effect.

Is it OK to evaluate a design value directly?

[2]P

See §2.6.4.1(4)P.

Given the absence of partial factors for rock mass parameters, calculation of design values using partial factors is not possible at this stage.

[3]

Assessing design values directly is the only option for rock masses, as for instance Annex E. Thus, this item should be more developed.

#### 2.4.6.3 Design values of geometrical data

[1]

Is this the case for rock engineering structures? This needs to be more clearly explained.

### 2.4.7 Ultimate Limit States

This seems to have been developed by considering soils. Can it be extended to rocks? This approach focuses on failure mechanisms previously identified, but in rocks the actual failure mechanisms may differ from these.

#### 2.4.7.1 General

[1]P

Replace “rock” with “rock mass”.

This Clause seems not to be written for rock mechanics, and so needs to be updated.

[2]P

See §2.4.6.2.

[4]

What should the values be? What is ‘abnormal’, ‘unusual’ or ‘exceptional”?

[5]

See §2.4.6.1(4)P.

[6]

Guidance is required as to what this means for rock mechanics.

#### 2.4.7.2 Verification of static equilibrium

[2]P

See §2.4.6.1(4)P.

#### 2.4.7.3 Verification of resistance for structural and ground limit states in persistent and transient situations

##### 2.4.7.3.2 Design effects of actions

[2]

Guidance is needed on what “unreasonable or even physically impossible” means.

In all ground/structure interaction problems like retaining structures and rock support, the effect of actions cannot easily be defined. The geotechnical action will depend on the stiffness and strength of the support and structure. The design value of both ground or water pressures can all be unreasonable or even impossible. A solution is to use derived values and a fully probabilistic approach.

##### 2.4.7.3.4 Design Approaches

The existence of different design approaches, that countries are free to chose and fix in their National Annex, for each type of geotechnical construction, is awkward and detrimental for the widespread understanding and use of EN1997. Steps towards unification of the design approaches should be taken.

###### 2.4.7.3.4.1 General

[1]P

See 2.4.6.2.

###### 2.4.7.3.4.4 Design Approach 3

[1]P

In Norway, this is the only design approach that can be used for rock engineering.

#### 2.4.7.5 Verification of resistance to failure by heave due to seepage of water in the ground

[1]P

Why only heave? The Limit State HYD also involves internal erosion and piping. These issues can be important for the physical properties of rock masses.

### 2.4.9 Limiting values for movements of foundations

Why only foundations? It maybe the most common situation for serviceability limit state, but others exist.

## 2.5 Design by prescriptive measures

With regard to current rock engineering practice, this section is poorly developed. It is very important clarify what “prescriptive methods” are and to which types of geotechnical constructions – in terms of their complexity – they can be applied. This is particularly important in rock engineering, where design by prescriptive measures is often used. Do empirical rules coming from rock mass classification systems, based on classification indices, geometry of construction and required reliability level fall into this type of “design by prescriptive measures”?

## 2.7 Observational method

With regard to current rock engineering practice, this section is poorly developed.

A distinction should be made between “observation” and “monitoring”: generally, ‘monitoring’ should be changed to ‘observation’

[1]

“When prediction of geotechnical behaviour is difficult” is not clearly defined. It may be clarified by adding: “If there are difficulties verifying the limit states with other methods, it may be appropriate to apply the Observational Method.”

[2]P

The behaviour must be defined by in terms of relevant control parameters which are observable. It is the behaviour of these control parameters which should give the acceptable limits to the possible and actual behaviours.

Replace “response time of the instruments” with “response time of the observations”.

[5]P

“Monitoring equipment” should be changed to “observational process” and the Clause reworded accordingly.

## 2.8 Geotechnical Design Report

[1]

Replace “Methods of calculation” with “method of verification of the limit states”.

[3]

Delete or Monitoring, See below

[4]P

It is not clear whether ‘monitoring’ here refers to the monitoring required in §2.7, or monitoring of ground behaviour (e.g. annual variation in groundwater levels). The paragraph should be split into two: one part should dealing with what shall be stated about supervision and monitoring for those cases where verification of the limit states have been carried out by calculations or prescriptive measures, and the second part dealing with limit states verified by the observational method, see §2.7(2)P.

[5]

See § 2.8(4)P. It should also stated how the construction should be supervised.

# 3 Geotechnical data

## 3.1 General

[3]P

Laboratory testing is not always needed.

[4]

Add some about monitoring system in general and in rock mechanics in particular

EN1997 Part 2 is incomplete with regard to rock mechanics tests (e.g. abrasivity). EN1997 Part 2 should refer to the ISRM Suggested Methods, which are generally regarded as standards in rock mechanics.

## 3.2 Geotechnical investigations

### 3.2.1 General

[1]P

It is difficult to obtain characteristic values of rock masses from ground investigations. As a result, “the characteristic values of the ground parameters to be used in design calculations” should be replaced with “derived values of the ground parameters to be used in verifications of the limit states”.

[2]P

This needs to be revised to reflect the requirements of investigation in rock masses.

There is no clear connection between Geotechnical Category and the type and amount of ground investigations.

[3]

Replace “large or unusual structures” with “large or unusual structures or parts thereof”.

Some guidance on what comprises these unusual or large structures would be useful.

[4]

This is not clear.

[5]

This is very important in rock engineering, due to the heterogeneity of rock masses.

However, as this is “to enable the design assumptions to be verified during construction”, it is unrelated to pre‑construction investigations. Should this Clause be part of monitoring?

### 3.2.3 Design investigations

[3]P

The paragraph is not applicable when observational methods are applied to verify the limit states – in such cases “before the start of final design makes no sense”. It should state that “the information required for an adequate design depends on the method of verification”.

In many cases in rock engineering, the final investigation takes place during excavation!

[6]P

This is not always possible, so replace “shall” with “shall, where feasible,”.

[7]P

As §3.2.3(6)P.

[8]

In many cases this is not possible (e.g. buried water courses, water‑bearing zones within rock masses).

## 3.3 Evaluation of geotechnical parameters

### 3.3.1 General

[1]

What does “comparable experience” mean?

### 3.3.2 Characterisation of soil and rock type

[1]P

What does this mean here? What is the intention of this statement?

[4]

This is a very poor description. Either it should simply refer to other recognised characterisation methods (e.g. ISRM, Geological Society of London) or the best of these other schemes brought together here.

[5]

As §3.3.2(4).

### 3.3.3 Weight density

[2]

Undisturbed sampling not necessary for rock – the state‑dependence of soil weight density does not apply to rock. Is material recovered from within a weathered profile soil or rock?

### 3.3.6 Shear strength

This refers only to soils; any relation to intact rock, rock discontinuities and rock masses has been ignored. Evaluation of shear strength of a rock mass is one of the most important issues for design in rock masses.

### 3.3.7 Soil stiffness

This refers only to soils; any relation to intact rock, rock discontinuities and rock masses has been ignored.

### 3.3.8 Quality and properties of rocks and rock masses

This Clause recognises the significance of heterogeneity in rock masses and that parameters should be derived with due consideration to it. However, it focuses on quantitative assessment of rock properties, and should be expanded to include the qualitative, subjective correlations often (always?) applied in rock mechanics to derive rock mass parameters. Some guidance, or at least acknowledgement, should be incorporated in to the next revision of EC7 on the use of the numerous empirical correlations used to derive parameters to characterise fractured rock masses.

#### 3.3.8.1 General assessment

[1]P

See §3.3.2(4).

Replace “following characteristics of the joints” with “following characteristics of any discontinuities”. In addition, weathering of the rock mass and groundwater conditions needs to be included.

Improve the vocabulary: are width and aperture the same thing?

[3]

Where is classification quoted in EN 1997-2?

[4]P

Is this meant to be weathering?

It is of much more general concern than just foundations.

[5]

Swelling can occur in minerals other clay, and can be due to stress changes.

#### 3.3.8.2 Uniaxial compressive strength and deformability of rock materials

There is no reference to triaxial testing, which is critical for determining a strength criterion.

Refer to the ISRM Suggested Methods.

These instructions should be extended to all laboratory tests on rock material not only to UCS.

#### 3.3.8.3 Shear strength of joints

Cyclic tests are required in order to assess behaviour under seismic actions.

[1]P

This refers to tests, but normally tests are performed at small scale in the laboratory, not at engineering scale. Reference is required to scale effects and in-situ tests.

Boundary conditions (constant stiffness, constant load, constant displacement) needs to be reported.

[2]

### 3.3.9 Permeability and consolidation parameters of soil and rock

#### 3.3.9.2 Permeability parameters of rock

This presentation is overly simple; it needs to be expanded.

### 3.3.10 Geotechnical parameters from field tests

Currently only typical soil tests are considered. It should be extended to include the typical rock mechanics’ assessments of tilt, point load index, and Schmidt hammer tests.

All in situ tests for rock masses and rock discontinuities are completely missing. Plate loading tests may be useful for rock mass deformability determination.

#### 3.3.10.6 Dilatometer test

EN 1997-2 mentions the Flexible dilatometer test (FDT), which can be a rock dilatometer test (RDT) and soil dilatometer test (SDT). Both are relevant in the context of EN1997. Here, “dilatometer test” refers to soils only, which is wrong.

## 3.4 Ground Investigation Report

### 3.4.1 Requirements

[1]P

The Ground Investigation Report can be separated from the Geotechnical Design Report.

[2]P

This is wrong, because EN1997 Part 2 is incomplete.

### 3.4.2 Presentation of geotechnical information

Susceptibility of rock to freeze/thaw should be included.

# 4 Supervision of construction, monitoring and maintenance

## 4.1 General

Supervision and monitoring is strongly connected to the method used for limit states verification. This Section should therefore be divided into three parts: one general (say, §4.1.1); one dealing with supervision and monitoring if calculations or adoption of prescriptive measures have been applied (§4.1.2);; and one dealing with the requirements if the observational method has been applied (§4.1.3)

[1]P

Move to §4.1.1.

[2]P

Replace “any monitoring” with “any observation or monitoring” and move to §4.1.1.

[3]

Applicable when limit states have been verified by calculation or prescriptive measures; move to §4.1.2.

[4]

Applicable when limit states have been verified by Observational Method; move to §4.1.3.

[5]P

Applicable when limit states have been verified by Observational Method; move to §4.1.3.

[6]

Move to §4.1.1.

[7]P

Move to §4.1.1.

[8]P

Move to §4.1.1, if it is added that it is the level, precision and quality of the observation and monitoring which shall be at least as assumed in the design. Delete the part “… and shall be consistent with the values selected for the design parameters and partial factors”, is this is irrelevant.

Needs to be integrated with Annex J, and reference to monitoring of rock block movement needed.

## 4.2 Supervision

### 4.2.2 Inspection and control

[3]

Measurements of ground properties are not always easy in rock engineering; however, if “measurements” is synonymous with “observation”, then this be acceptable.

### 4.2.3 Assessment of the design

This heading can be confused with the Observational Method. This would be better as §4.3 Verification of design assumptions, with the existing §4.3 being renumbered to §4.3.1.

[2]

Needs to explicitly include rock mechanics.

## 4.3 Checking ground conditions

In this cases where the material being excavated is to be partitioned into a number of rock mass classes, this checking process should mean ‘assign the material to one of the pre-determined rock mass classes”.

### 4.3.1 Soil and rock

[5]

Techniques such as Measurement While Drilling need to be included.

## 4.4 Checking construction

The checking of construction is part of supervision of the work; this should be moved to §4.2.

## 4.5 Monitoring

For all geological materials, monitoring systems must be designed in terms of characteristics such as sensitivity, accuracy, precision, frequency of measurements and range of measured values.

[1]P

Monitoring is part of the general requirements stated in §4.1, and as such §4.5(1)P should be moved in order to clarify the differences between monitoring and application of the Observational Method.

[4]

Displacements along, or opening of, discontinuities needs to be included.

# 5 Fill, dewatering, ground improvement and reinforcement

## 5.1 General

[2]P

Dewatering and ground improvement using techniques such as grouting and ground freezing are used in rock engineering as independent activities, and may therefore be better introduced as design situations.

## 5.5 Ground improvement and reinforcement

Currently, §5.5 is specifically written for soil, and so needs to be expanded to include rock engineering procedures.

# 6 Spread foundations

This section focuses on soil, which is logical. However, it also refers to the possibility of failure through pre-existing bedding planes, faults or joints, and provides, by means of Annex G, a sample procedure to estimate the ultimate bearing capacity of rock masses. Annex G is overly simple, and needs to be removed. There are published analytical solutions based on non linear failure criteria suitable for discontinuous rock masses. A method is also required that is applicable for those cases where discontinuities do not play a relevant role (e.g weak intact rock such as chalk, some sandstones).

## 6.5 Ultimate limit state design

### 6.5.2 Bearing resistance

#### 6.5.2.2 Analytical method

[1]

A non linear failure criterion for rock masses is necessary.

[3]P

In the Annex a sample analytical calculation for bearing resistance of a discontinuous rock masses should be given.

[5]P

For the reverse situation, of strong material overlying a weak formation, a sample calculation should be given in the annex.

## 6.7 Foundations on rock; additional design considerations

[2]

The idea that “spread foundations on rock may normally be designed using the method of presumed bearing pressures” is a typical view held by soil mechanics engineers. It is a dangerous statement. This Clause needs to be rewritten to make clear the problems specific to rock masses, such as the effect of discontinuities or superficial weathering.

See also §6.

# 7 Pile foundations

End bearing piles on rock, including caissons, should be included in this section.

# 8 Anchorages

## 8.1 General

### 8.1.1 Scope

This section is not at all applicable to rock support and rock reinforcement; presumably the recently re‑written version is.

## 8.7 Suitability tests

[4]

Testing of rock bolts is covered by an ISRM Suggested Method. The equivalence of this SM and EN1537 needs to be checked.

# 9 Retaining structures

This Section needs to also include (a) structures where the rock mass is reinforced sufficiently to become a retaining structure and (b) structures made of rock products (e.g. gabions or dry-stone retaining walls).

## 9.1 General

### 9.1.1 Scope

It is not clear if the scope includes a typical rock engineering support system of rock bolts with reinforced shotcrete.

### 9.1.2 Definitions

The constant use of the word “soil” should be reviewed.

#### 9.1.2.3

Would “structures with multiple rows of ground and anchorages or soil nails” also include shotcrete walls with rock bolts?

## 9.2 Limit states

[1]P

[2]P

[3]P

[4]

## 9.3 Actions, geometrical data and design situations

### 9.3.1 Actions

Include the effects of blasting (e.g. vibrations, stress waves, gas pressure) In Norway some years ago, blasting pushed a rock block into quick clay and induced a landslide.

# 10 Hydraulic failure

What is the definition of ‘failure’? EN1997 is a limit state code, and so this title should be reworded to remove the word ‘failure’.

As written, this is only pertinent to soils. There are many cases in rock masses where water flow and pressure leads to occurrence of a limit state.

## 10.1 General

[1]P

Measures to prevent the negative impact of lowering the ground water level have to be included in rock engineering designs. This loading case is not mentioned.

[3]P

Rock permeability has to be considered.

[5]P

It is the flow velocity that produces internal erosion, not the gradient. Rock engineering measures such as grouting increase the gradient but reduce the velocity.

[6]

Include grouting.

## 10.3 Failure by heave

Behaviour of rock needs to be included.

## 10.4 Internal erosion

[6]P

Behaviour of rock needs to be included.

# 11 Overall stability

## 11.2 Limit states

‘All limit states… shall be considered’. This is easy to state, but difficult to perform in rock mechanics, so this is usually one of the critical points in rock engineering slope design.

## 11.4 Design and construction considerations

[10]

Rock support and reinforcement measures like bolting, and surface protection like shotcreting.

## 11.5 Ultimate limit state design

### 11.5.1 Stability analysis for slopes

A whole book would be appropriate to deal with this topic (Hoek & Bray, to cite a classic). The clauses are satisfactory but they do not reflect the complex nature of topic.

[3]

‘It should be considered: … occurrence and inclination of discontinuities’. This is poorly written, as it will be better to account for the structure of the rock mass.

Rock layering is missing.

[4]

‘Failure surfaces... planar, circular and more complicated shapes…’. This seems to be referring to sliding surfaces that emerge due to the effect of actions, not pre‑existing sliding surfaces. Pre‑existing surfaces (e.g. discontinuities in rock, listric faults in soils) may lead to complex mechanisms, which the Code seems to incorrectly group as complicated failure shapes.

[8]

‘Existing failing slopes….. circular and noncircular failure surface. Partial factors normally used for overall stability analysis then need not to be appropriate.’ Is this a kind of disclaimer pointing to the fact that when partial factors have not been defined, application of the partial factors approach is not possible?

[12]

As noted, existing gravity loads can be favourable or unfavourable, so upper and lower values of characteristic values (weight density) should be used. It seems that in rock mechanics actions can be actions or resistances according to the type of mechanisms. This could complicate the application of partial factors to rock related instability mechanisms.

### 11.5.2 Slopes and cuts in rock masses

[1]P

‘…translational and rotational modes, isolated blocks or large parts of rock masses, rockfalls, seepage…’ Very general, very vague… A book is needed to comprehend all the mechanisms indicated in those lines. This needs to be substantially revised.

Ice pressures should be mentioned.

Toppling instability is not included in this Principle, but should be.

## 11.7 Monitoring

Specific aspects of monitoring rock slopes needs to be included.

# A Partial and correlation factors for ultimate limit states and recommended values

## A.3 Partial factors for structural (STR) and geotechnical (GEO) limit states verification

### A.3.2 Partial factors for soil parameters (gM)

Add in table A4 factors for rock parameters?

# G A sample method for deriving presumed bearing resistance for spread foundations on rock

This entire Annex needs thorough revision. Points of note:

– In some circumstance it may be appropriate to use correlations with rock mass classification values;

– It is suggested to give some references related to the proposed method, even though it’s just informative.

– In (1), in the 2nd line it says ‘presumed bearing resistance’ and in the last line of the same paragraph it says ‘presumed bearing pressure’. If they refer to the same concept they should be named the same.

– The validity of the proposed method is questionable due to different aspects, mainly:

a) In (1), in the 1st line it says ‘For weak and broken rocks ...’.

b) The title of Table G.1 is ‘Grouping of weak and broken rocks’, but there are included ‘pure limestones’, ‘carbonate sandstones of low porosity’, ‘igneous rocks’, and other rock types of usually high strength.

c) In the heading of figure G.1 there is a classification from ‘a) very weak rock’ to ‘e) strong rock’.

– In notes 5 and 6 of figure G.1 is written ‘allowable bearing pressure’, but it seems it should be ‘presumed bearing resistance’.

– It may be appropriate to configure Table G1 as two tables: one for weak rocks and another for discontinuous rock masses.