Critical review of EC7 concerning prescriptive measures for rock mechanics design

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ABSTRACT: Eurocode 7 (EC7) implies that each geotechnical design situation shall be verified; that no relevant limit state conditions are exceeded. For this, one or more of four suggested design methods given in EC7 can be applied. One of these methods is prescriptive measures, which requires that documented experience and normal, well-known practice, provides satisfactory stability. EC7 allows using such design method when no calculation models are available or necessary.

Prescriptive measures involve conventional and general rules or practice in the design and may be used where comparable experience makes design by calculations unnecessary. Information of local experience is seen as particularly relevant.

As most classifications systems are systematic documentation of earlier experience of rock constructions, they qualify as prescriptive measures. The paper shows which parts of e.g. the Q-system that can be suitable for this.

The Geotechnical Category (GC) in EC7 is an important part of the rock design. The paper presents ground conditions where prescriptive measures may be used in rock engineering, design and construction.

1 INTRODUCTION

The Eurocodes were initiated for bridge construction, and have then been applied in more and more applications, such as in soil mechanics and finally in rock engineering. They serve as reference documents for the following purposes:
" - as a basis for specifying contracts for construction works and relating engineering services;
- as a framework for drawing up harmonised specifications for construction products."

Further, *"the Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both traditional and an innovative nature."*

Eurocode 7 (EC7) *"is intended to be applied to geotechnical aspects of the design of buildings and civil engineering works. It is subdivided into various separate parts" "EN 1997 is concerned with the requirements for strength, stability, serviceability and durability of structures. Other requirements, e.g. concerning thermal or sound insulation, are not considered."*

Though the EC7 covers both soil and rock engineering, there are significant differences between constructions in the types of materials.

Ideally, a rock mass is composed of a system of rock blocks separated by joints (discontinuities) forming a material in which all elements behave in mutual dependence as a unit.

The complicated structure of the rock mass and the wide range of its applications cause challenges and problems in rock engineering and construction involve considerations that are of relatively little or no concern in most other branches of engineering. A major challenge is the uncertainties regarding geological setting and conditions as well as the geotechnical parameters. Therefore, 'engineering judgement' and experience often play an important role in rock engineering and design.

Important in all works involving rock mechanics, rock engineering and design are the quality of the geo-data that form the basis for the calculations and estimations made.

The construction materials in rock constructions as well as the type of construction structure are different. In addition, testing of the construction materials is difficult/impossible. This causes challenges when rock design and construction are to be included as a part of a common geotechnical Eurocode.

A design requirement in EC7 is that no relevant limit state is exceeded for each geotechnical design situation, as defined in EN1990:2002. One, or a combination of the following design methods can be applied for this:

- calculations
- prescriptive measures,
- experimental models and load tests,
- observational method

2 WHAT ARE PRESCRIPTIVE MEASURES?

According to Merriam Webster dictionary,

- Prescriptive: rules of usage founded on long-standing custom.
- Measure: an estimate of what is to be expected (of a situation).

This shows that prescriptive measures are associated with experience, empirical methods and well-accepted practical geotechnical solutions.

Empirical methods are simply stated to be correlations between rockmass conditions and rock support and construction. Although the prediction of empirical methods is qualitative, the procedure leading to them can be either quantitative or qualitative. This procedure is important in assessing the validity of the techniques. According to Einstein (1978), empirical models are primarily found in two applications:

1. Before construction ('limited' geological information):
   - design of initial support,
   - determination of construction procedure,
   - preliminary design of final support

2. During construction (limited time):
   - determination of (details of) initial support or adaption of initial support,
   - determination of construction procedure,
   - design of final support in rare instances

Parameters are determined from boring logs, outcrop observations, maps, general knowledge of the area, and from observations in tunnels or in excavated cuttings. Some limited physical testing may also be carried out. Only a limited number of parameters can be determined from boreholes, outcrops and maps (particularly concerning conditions at tunnel grade).

In contrast, observations in the tunnel can detect the real or true rockmass conditions. Parameters, that can be easily obtained from outcrops and boreholes or quickly observed (or measured) in the tunnel, are desirable.

Rockmass classification systems are by most practitioners considered a typical empirical method (e.g. Hoek 1999, Einstein et al., 1979) as they are largely based on experience from earlier rock excavations. They have been used more and more over the last 40 years.

Pre-determined, experience-based prescriptive measures comprising suitable conservative modules of works have for many years been extensively used by the Geotechnical Engineering Office (GEO) in Hong Kong. These solutions are applied without the need for detailed ground investigations and design analyses. The following reports can be found at GEO's homepage:

- Application of Prescriptive Measures to Soil Cut Slopes (Wong et al., 1996)
- Application of Prescriptive Measures to Slopes and Retaining Walls (Wong et al., 1999),
- Prescriptive Design of Skin Walls for Upgrading Old Masonry Retaining Walls (Wang et al., 1999)
- Prescriptive Soil Nail Design for Concrete and Masonry Retaining Walls (Lui et al., 2005)
- Guidelines on the Use of Prescriptive Measures for Rock Cut Slopes (Yu et al., 2005)
- Prescriptive Measures for man-made slopes and retaining walls (Chenung et al., 2009)

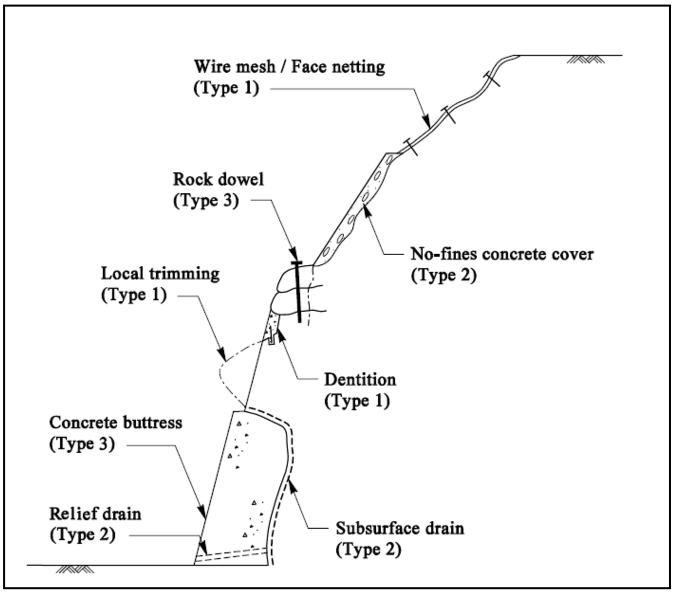

Figure 1: Schematic diagram of typical prescriptive measures for rock cuts (Yu et al., 2005).

They are all guidelines for specific geotechnical engineering areas. The background for each of them is a review of many cases, as for example for rock cuts where more than 100 slopes are reviewed. The guidelines focus on application merits and past experience. Some items for use in rock slopes are shown in Figure 1.

The guidelines give recommended procedures for applications and record sheets that have to be filled in. It is also stated that prescriptive measures should be designed by professional qualified engineers and experienced in Hong Kong (such as Registered Professional Engineer), and the same are also applied for construction review. All works must be properly documented.

Other examples on applications are foundation of power masts for power grid in Norway. This system was developed in 1978, based on Prescriptive Measures (NGI, 1978a,b). It is under update, and will include four ground types and four types of foundation types, where two of the foundation types are based on prescriptive measures and two on design by calculations.

3 DESIGN BY PRESCRIPTIVE MEASURES IN EC 7

Prescriptive measures in EC7 consist merely on application rules, no principles. The rules given under prescriptive measure in EC7 are relativity short compared with the other methods that may open up for understandings that are more individual.

EC7 only gives two application rules; of which the first is:

(A)"*In design situations when calculation models are not available or not necessary, exceeding limit states may be avoided by the use of prescriptive measures.* (B)*These involve conventional and generally conservative rules in the design, and attention to specification and control of materials, workmanship, protection and maintenance procedures*".

What does EC7 mean here? The first sentence (A) states that in design situations when calculation models are not available or not necessary, prescriptive measures can be used to avoid that limited states are exceeded. Some situations where calculation models are not necessary can be:

- A long tunnel with rock support, where only a few sections have been calculated, the remaining sections will be designed according to Prescriptive measures or the Observation method.
- A rock cut where a minor key block is exposed and practice is used to design the rock support.

Are these examples acceptable for using prescriptive measures? How can we be sure that none of the limited state cases exceeds? Just because the stability still is acceptable?

The (B) sentence says that these (design situations) involves conventional and generally conservative rules in the design, and attention to specification and control of material, workmanship, protection and maintenance procedures. What do EC7 mean with "*These involve conventional and generally conservative rules in the design*" ? Is this about the design situations or prescriptive measures? The rest seems quite clear.

The second application rule in EC7 is:

"Design by prescriptive measures may be used where comparable experience, as defined in 1.5.2.2 makes design calculations unnecessary. It may also be used to ensure durability against frost action and chemical or biological attack, for which direct calculations are not generally appropriate".

This is an alternative way of using prescriptive measures, and the most interesting part here is the definition of comparable experience as defined in 1.5.2.2 of EC7:

"*documented or other clearly established information related to the ground being considered in design, involving the same types of soil and rock and for which similar geotechnical behaviour is expected, and involving similar structures. Information gained locally is considered to be particularly relevant*".

The text under prescriptive measures has to be more extensive than this in the planned, updated version of EC7. This is further discussed in the following chapter.

4 WHEN CAN PRESCRIPTIVE MEASURES BE APPLIED?

According to Einstein et al. (1979), empirical methods, and consequently prescriptive measures should attempt to satisfy the following, in some way incompatible objectives:

1. They should promote economical, yet safe designs.
2. They must be correctly calibrated against test cases and those test cases must be representative of the field of application of future use.
3. They should be complete in that all relevant factors are included, yet they must be practical in that parameters can be determined and with acceptable certainty.
4. They should have general applicability and robustness, yet they must be recognised as fundamentally subjective.

Figure 2 shows how Hoek (1999) considers the use of empirical methods (and consequently prescriptive measures) in rock engineering. The design method is selected depending on the ground composition and behaviour.

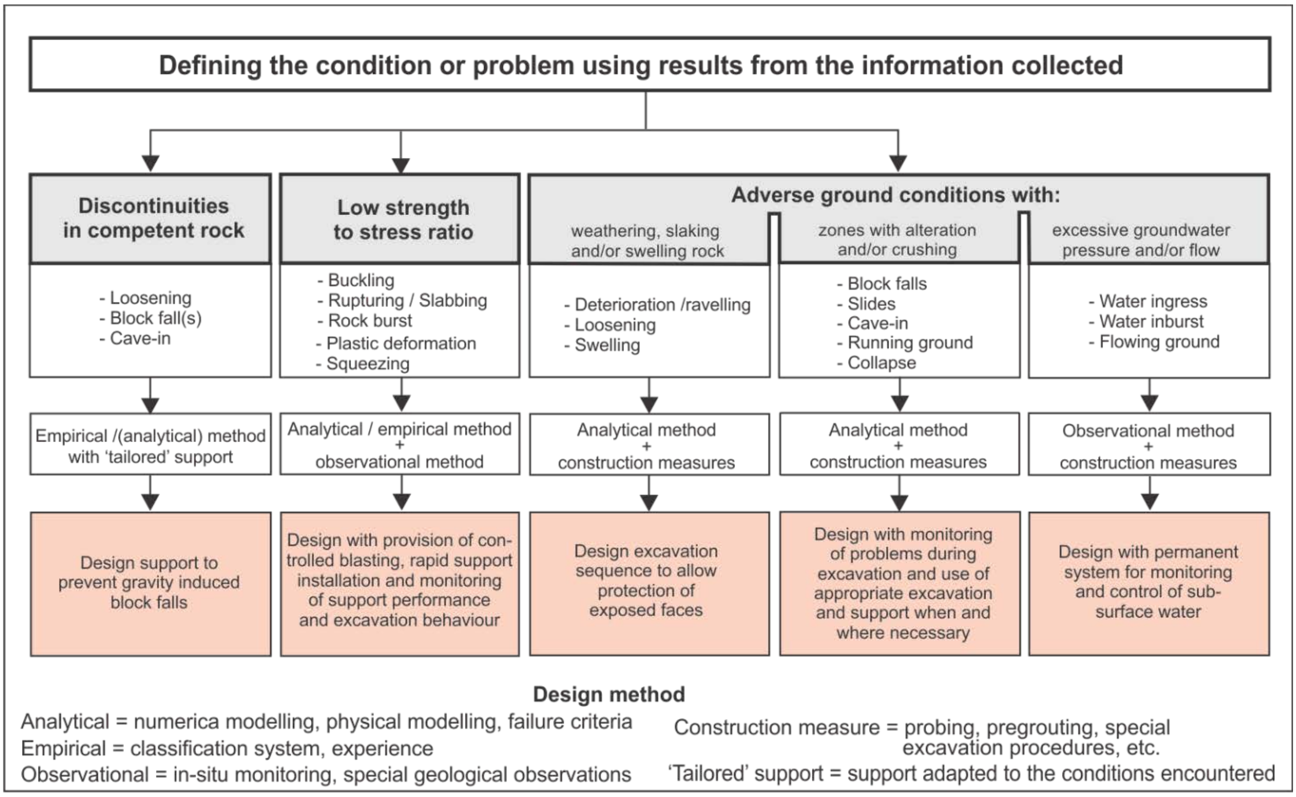

Figure 2: Design methods based on ground conditions and behaviour (developed from Hoek, 1999)

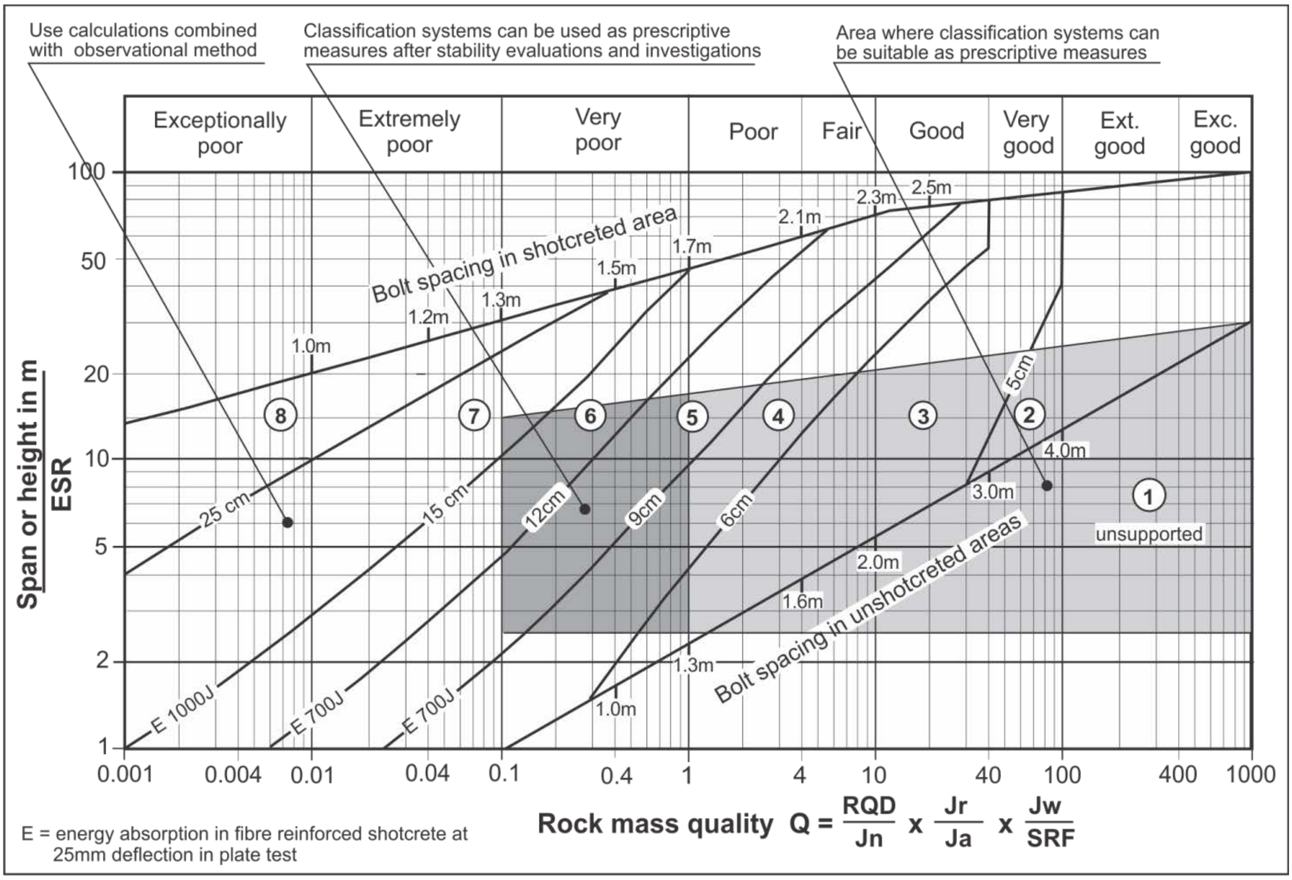

Figure 3: Where the Q classification system can best be used for design in the EC 7

Table 1: Determination of Geotechnical Category when the ground conditions are uncertain. The ground uncertainty is assumed based on the investigations results.

Excavation Risk	**Types of Construction. Examples**	**Assessed degree of Ground Uncertainty** (before encountered)		
		Low	Medium	High
Low	- Foundations	1	1 / 2	2
Medium	- Foundations where blasting is involved - Tunnels and small - moderate rock cuttings	1 / 2	2	2 / 3
High	- Undersea tunnels - Caverns with large span - Low rock cover of underground excavations in susceptible areas - High rock cuttings; anchoring for suspension bridge - Excavation may influence on nearby settlements	2	2 / 3	3

Degree of Ground Uncertainty (before the ground has been encountered in the excavation):

Low: Clear and simple geology and ground conditions. Ground parameters can be easily found. Experience from similar ground conditions can be documented.

Medium: Clear geology and ground conditions. Methods exist to assess ground conditions and for dimensioning. Acceptable experience from other similar ground conditions and constructions can be documented.

High: Unclear geology and/or ground conditions with potential for problematic tunnel excavation. There are limited possibilities to assess the ground conditions.

Excavation Risk:

Low: No risk. Safe, straight forward excavation.

Medium: Some probability for loss.

High: Possibility for severe accident(s) and loss. Accidents and loss can be injuring incidents and/or disasters, such as collapse, water ingress, damage to nearby constructions, etc.

Table 2: Determination of Geotechnical Category when the ground conditions are known (after encountered in the excavation).

Level of Usage Requirements	**Types of Usage. Examples**	**Ground Quality**		
		Good	Fair	Poor
Low	- Simple foundations - Water tunnels, mine drifts - Moderate rock cuttings	1	1 / 2	2
Moderate	- Partly complicated foundations - Low traffic road- and railway tunnels - High rock cuttings, storage caverns in rock	1 / 2	2	2 / 3
High	- Complicated foundations; Very high rock cuttings - High velocity railway tunnels and heavy traffic road tunnels - Underground railway and hydropower stations - Areas with potential for severe landslide - The construction may cause damage on nearby settlements	2	2 / 3	3

Level of Usage Requirements:

Low: Limited requirements as long as the project functions during its lifetime. For water tunnels, e.g., downfall of fragments and single blocks are often accepted.

Moderate: Minor maintenance/control is accepted within lifetime of construction.

High: No damage or deterioration of the construction is accepted during its lifetime.

Ground Quality is defined according to a preset classification. Ground classification systems may be used for this.

Classification systems are empirical systems and include quantitative values for the rock mass quality, geological conditions and geometrical design. One of the most used classification systems is the Q-system. This system is based on review of rockmass conditions and rock support in more than thousand tunnels and caverns.

Figure 3 shows how the use of empirical methods in Figure 2, may be used with the Q-system. This means that for Q-values larger than 1, prescriptive measure can be suitable, while for Q-values between 0.1 to 1, additional stability evaluations should be applied. For Q less than 0.1 the design should be based on a combination of the observation method, preferably supported by calculations. The limit for the Q-values is not definitive. This principle will probably also be valid for several other classification systems.

In EC7, the design method is to be selected on basis of the Geotechnical Category (GC). However, also the ground conditions, i.e. the ground risks (challenges and difficulties/uncertainties) will strongly influence during excavation and the ground quality on usage or operation requirements of the project.

As the ground conditions along the tunnel cannot be determined before excavation a main issue is the geological uncertainties (and consequently excavation risks). This has to be accounted for in the GC as shown in Table 1.

After the tunnel or cavern has been excavated and the ground conditions are known, the qualities of the ground along the tunnel form the main issue in the design of the permanent support as well as in the maintenance control plans. Consequently, this should be a main input in the selection of the GC, see Table 2.

The consequences of this is that a project e.g. may use GC = 3 during planning and GC = 2 for design of permanent rock support. As the ground conditions mostly will vary along a tunnel, the GC may also vary along the tunnel.

5 CONCLUSIONS

Prescriptive measure is one of the four design methods that can be applied when no calculation models are available or necessary. It comprises pre-determined, experienced-based and suitably conservative solutions, without the need for detailed ground investigations and design analysis. The EC7 application rules give very short and weak guideline for using this method.

Nevertheless, the method is very important in the design of tunnels in medium to good stability rockmasses with possibilities to use rockmass classification systems.

EC7 does not give an appropriate description for selection of the Geotechnical Category (GC). The paper shows some ideas how GC can be found and used.

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