Eurocode 7 (EC7): On Geotechnical Categories, Design and Supervision

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1. Geotechnical Category

The Geotechnical Category used in Eurocode 7 defines the project and sets recommendations and requirements for planning, control and construction. Thus, it influences the extent of:

- The documentation of the ground conditions.
- The engineering and design of the rock excavation.
- The control and the supervision of the investigations and the design.
- The inspection and the monitoring of the rock construction works.

The minimum requirements for geotechnical investigations, design verification and construction control checks are related to the risk associated with the structure. Three Geotechnical Categories (GC) 1, 2 and 3 act as guidelines for classifying the degree of risk. For rock constructions, the risks are associated with an assessed degree of ground uncertainties and complexity of the construction work related to potential, severe accidents and losses, both for the construction workers and the environment.

During planning, when the ground conditions along the tunnel cannot be determined, a main issue is the geological uncertainties and consequently construction risks. This can be accounted for in the GC, as shown in Table 1.

Table 1: Geotechnical Categories before excavation for rock engineering and excavation planning. (suggested by Stille and Palmström, 2018)

BEFORE EXCAVATION for planning		**Geotechnical Category**		
Consequences class (CC)	**Examples. Typical rock constructions**	**Ground Uncertainty**		
		low	medium	**High**
CC1 Low	- Simple foundations on rock - Low – moderately high rock cuttings - Tunnels of small size (< 4 m span)	GC1	GC1 / GC 2	GC2
CC2 Medium	- Complicated foundations on rock - High to very high rock cuttings - Large tunnels (4 to 15 m span) - Environmental requirements	GC1 / GC2	GC2	GC2 / GC3
CC3 High	- Undersea tunnels, all sizes - Unlined pressure tunnels, all sizes - Strict environmental requirements - Large caverns or very large tunnels (span > 15m) - Tunnels with limited rock overburden	GC2	GC2 / GC3	GC3

Consequences classes (in accordance with EN 1990):

CC1: **Low** consequences for loss of human life, or economic; social or environmental consequences are **small or negligible**

CC2: **Medium** consequences for loss of human life; or economic; social or environmental consequences are **considerable**

CC3: **High** consequences for loss of human life, or economic; social or environmental consequences are **very high**

Classes of Geological and Ground Uncertainty (before excavation)**:**

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

Medium: Clear geology and ground conditions. Methods exist both to assess ground conditions and for dimensioning. Experience from construction in similar ground conditions 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 before excavation starts

For the permanent use of the structure, the ground conditions are known after the ground conditions have ben disclosed in tunnel or cavern. The main risk is related to the consequences and the probability of failure, which is related to the quality of the actual ground encountered in the tunnel. The ground quality will 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.

Table 2: Geotechnical Categories after excavation for design and installation of permanent support. (suggested by Stille and Palmström, 2018)

AFTER EXCAVATION for permanent works		**Geotechnical Category**		
Consequences class (CC)	**Examples. Typical rock constructions**	**Ground Quality**		
		good	fair	Poor
CC1 Low	- Simple foundations on rock - Simple to moderately high rock cuttings - Mine drifts. Test adits - Simple water tunnels	GC1	GC1 / GC2	GC2
CC2 Medium	- Complicated foundations on rock - High to very high rock cuttings - Access tunnels. Complicated water tunnels - Low to medium traffic tunnels - Storage caverns in rock	GC1 / GC2	GC2	GC2 / GC3
CC3 High	- Caverns with very large span - Unlined pressure tunnels/shafts - Excavations with strict environmental requirements - Heavy traffic tunnels - Underground stations in rock	GC2	GC2 / GC3	GC3

Consequences classes (in accordance with EN 1990):

CC1: **Low** consequences for loss of human life, or economic, social or environmental consequences **small or negligible**

CC2: **Medium** consequences for loss of human life; or economic, social or environmental consequences **considerable**

CC3: **High** consequences for loss of human life, or economic, social or environmental consequences **very high**

Classes of ground quality (after the ground has been encountered in the tunnel, shaft or cavern)**:**

Good: Good or very good ground conditions and stability as documented from tunnel mapping using e.g. classification systems (RMR, Q, RMi, etc.)

Fair: Fair ground conditions and stability as found from tunnel mapping and, if found necessary, supported by investigations

Poor: Poor or very poor ground conditions and stability as found from tunnel mapping and description supported by investigations and tests

The assessment of the Geotechnical Category is an interactive process. The preliminary GC assessed in the beginning of a project shall be checked and changed, if required, at each stage of the design and construction process. As the ground conditions mostly will vary along a tunnel, the GC may also vary accordingly.

The observational method can be applied in all geotechnical categories. Visual observations and monitoring of construction works, structure and surroundings are used to identify contingency actions and alterations of construction sequences. Beside their objective to verify the design, they involve elements, which can be regarded as tools for quality control. They may also be used to evaluating the long-term performance of the structure.

2. Design

The structure and its impact can be classified as both temporary and permanent. In Eurocode 7, the design can make use of one or a combination of the following four methods:

Use of Calculations	**Calculations** according to Eurocode are based on design values, which is the characteristic value divided with a constant partial factor defined in advance. This requires that the limit states functions are relatively simple and that the rank of influences of the parameters will not be changed from case to case. For many types of rock mechanics problems based on rock-structure interaction, this is not the case.
Adoption of Prescriptive Measures	Adoption of P**rescriptive Measures** is commonly used in rock mechanics. Rock mass classification systems based on experiences from case histories belong to this category. The rock support measures defined are adopted without calculations and is purely empirical based.
Experimental models and load tests.	**Experimental models** and load tests are not common in rock mechanics design.

An observational method	This is a common method for verifying the design in rock mechanics. An essential part of the **Observational Method** is that the interactive design process is based on predefined contingency actions, which are linked with results from the observations made during excavation. The type of observations can be based on both measurements with instruments (monitoring) and visual inspections as tunnel/ground mapping. **Monitoring** is also used to check the validity of the design and ensure that the structure will continue to perform as required after completion. In principle, this is a part of the control work of the constructed structure and not a part of an interactive design process. It is important to distinguish between these two objectives of monitoring.

Every project is unique. Recommendations on the suitability of different design tools can only be indicative, especially as various combinations of the available tools may be appropriate. In a project with major consequences of delay or failure, the tools are often used to achieve an acceptable safe design, whilst for simple projects with low ground uncertainty, an approach based on empirical design methods or engineering judgement may be appropriate. Table 3 may act as guideline to determine suitable design tools for different Geotechnical Categories.

Table 3. Guideline for choice of design tools (from Stille and Palmström, 2018)

Geotechnical Category	**Design tool**		
	Use of **calculations**?	Adoption of **prescriptive measures**?	Use of an **observational method**?
1	No, generally not used.	Yes.	No.
2	Yes, analytical methods or numerical calculations are used as required.	Yes, often in combination with one of the other design tools.	Yes, based on visual observations of geology[1)] and measurements of behaviour as required[2)].
3	Yes, numerical methods are often used in combination with the observational method.	Yes, in combination with one of the other design tools.	Yes, based on visual observations of geology[1)] and measurements of behaviour[2)].

[1)] Geology here means mainly ground conditions.
[2)] Behaviour here includes deformation, convergence, etc. from monitoring and observations.

3. Supervision and control

Supervision and control of the planning, construction and workmanship is part of the risk handling. The extent depends on the complexity and risk associated to the design and thus the Geotechnical Category, see Table 4.

Table 4: GC and controls in various stages of a project (from Stille and Palmström, 2018)

Project Stage		Assessment of Geotechnical Category (GC)	Quality Controls (QC)[1)] and plans
Ground conditions **are assumed**	During investigation	A preliminary GC class (Table 1).	1. Quality Control of the field investigation works and testing procedures.
	After investigation, before design	Adjust GC class according to the investigations results (Table 1).	Make a plan for control of the design
	During planning (engineering and design)	The GC class according to the expected conditions along the excavation (Table 1).	2. Quality Control of design Work out plan for the control and inspection during excavation
Ground conditions **are known**	During excavation. Continuous information of ground conditions encountered	GC class for the ground conditions encountered supported by results from investigations performed (Figure 2).	3. Inspection during construction with: - QC of the ground conditions - QC of materials - QC of necessary investigations[2)] and tests - Monitoring of tunnel behaviour.
	After excavation	Adjust GC class (Table 2) after all investigations and test results have been collected	4. QC of permanent structures (design) -Supervision of the materials and works - Monitoring of tunnel behaviour.
	Before permanent use		Make a plan for maintenance and monitoring.

[1)] Control level depends on the actual GC. [2)] Investigations during and after excavation