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Technical note

An update of the "multiple graph" approach for the preliminary assessment of the excavation behaviour in rock tunnelling

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ABSTRACT

The so-called "multiple graph" approach is a useful tool for the preliminary assessment of excavation behaviour in rock tunnelling, as well as to rationally select the pre-defined support section type at the tunnel face, during the construction phase. In a simplified but rational way the potential typical deformation phenomena (hazards) for tunnelling in rock are identified through the quantification, in a logical sequence, of fabric (1), strength (2), competency (3) and self-supporting capacity (4) of a rock mass. Based on this preliminary analysis, the tunnel design can consequently focus on the detected potential problems, implementing with the required detail the most adequate methods of analysis and calculations. In this paper, the fundamental bases of the method are summarized and some new considerations are presented.

1. Introduction

The "multiple graph" approach (Russo, 2008) is a useful tool either for the preliminary assessment of the excavation behaviour in rock tunnelling and, as it has been experienced (Antolovic et al., 2013; Decman et al., 2013; Filipovic et al., 2013; Kontrec and Constandinidis, 2013; Palomba et al., 2013) to select the support class to be applied at the tunnel face on the basis of the pre-defined design criteria.

In particular, the so-called "GDE multiple graph", reported in Fig. 1, is a 4-sector graph based on the logical sequence of the engineering steps in Table 1.

In the next section, the technical bases of each equation are summarized, pointing out the relative background of each sector. At the same some new considerations are remarked.

2. The GDE multiple graph

As previously mentioned, the multiple graph is composed by 4 sectors (Fig. 1), each of them finalized to a user-friendly quantification of the corresponding properties presented in Table 1. The first graph is in the lower right quadrant and progress is clockwise through system.

2.1. Graph I: Estimation of rock mass fabric

Graph I (lower right quadrant in Fig. 1) estimates Rock Mass Fabric (GSI) based on Rock Block Volume (Vb) and Joint Conditions (jC).

When the rock mass can be reasonably treated as an equivalent-continuum, with isotropic geomechanical properties, the geo-structural features of rock masses can be expressed by a "fabric index" (Tzamos and Sofianos, 2007), which may be defined as a scalar function of two components: rock structure and joint condition. In the present case, the reference fabric index is the GSI (Hoek et al., 1995) and its estimate is derived by the method proposed by the author (Russo et al., 2007; Russo, 2009).

Such a new method for calculating the GSI has been developed taking into consideration the conceptual equivalence between GSI and JP (Jointing Parameter) of the RMi system (Palmstrom et al., 1996; Palmstrom, 2000), considering that both are used to scale down the intact rock strength (σ_c) to rock mass strength (σ_{cm}).

In fact, according with the two systems, we have:

$$\text{RMi} : \sigma_{cm} = \sigma_c * JP \quad (1)$$

$$\text{GSI} : \sigma_{cm} = \sigma_c * s^a \quad (2)$$

where s and a are the Hoek–Brown constants (Hoek and Brown, 1980; Hoek et al., 2002).

Therefore, JP should be numerically equivalent to s^a and given that for undisturbed rock masses (Hoek et al., 2002) one has:

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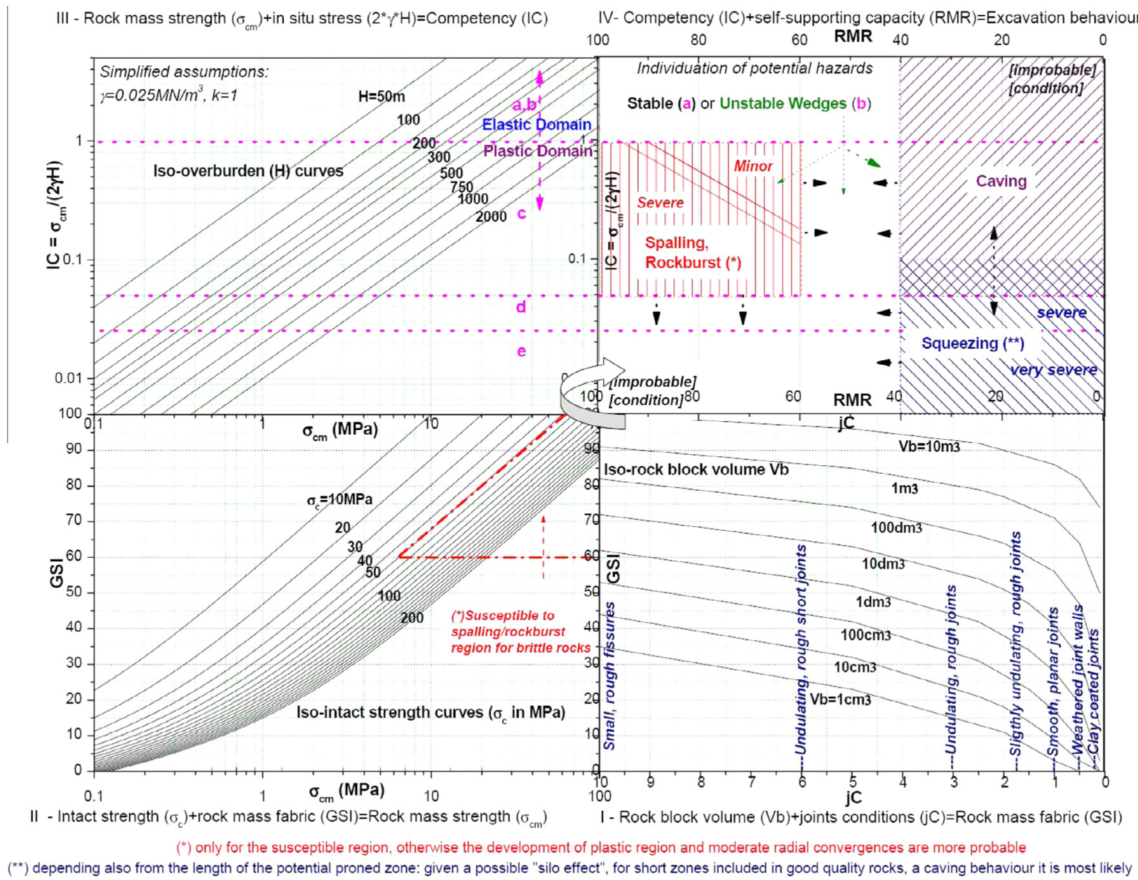

Fig. 1. The GDE multiple-graph for the preliminary setting of excavation behaviour. Notes: (*) Only for the susceptible to spalling/rockburst region for brittle rocks [IF = (σ_c/σ_t) > 8], otherwise a shear type failure should occur; the two new lines remarking the expected intensity of the brittle phenomenon are explained in the Section 2.4. (**) Squeezing involves pronounced time-dependent deformations and is associated to rocks with low strength and high deformability: otherwise, prevalent plastic deformations (no time-dependent) occur, frequently associated to caving; squeezing depends also from the length of the potential prone zone: given a possible "wall effect" (Anagnostou and Kovari, 2003), for short zones included in good quality rocks, a caving behaviour is most likely to occur. Symbols: σ_c, σ_{cm} = intact, rock mass strength (=σ_c*s^a); jC = joint condition factor, Vb = block volume; γ = rock mass density.

Table 1
Logical frame adopted for the identification of the excavation hazards.

Graph 1	Rock block volume + Joint Conditions = Rock mass fabric
Graph 2	Rock mass fabric + Strength of intact rock = Rock mass strength
Graph 3	Rock mass strength + In situ stress = Competency
Graph 4	Competency + Self-supporting capacity = Excavation behaviour (→Potential hazards)

$$s = \exp[(\mathrm{GSI} - 100)/9] \tag{3}$$

and

$$a = (1/2) + (1/6) * [\exp(-\mathrm{GSI}/15) - \exp(-20/3)] \tag{4}$$

a direct correlation between JP and GSI can be obtained, i.e.:

$$JP = [\exp((\mathrm{GSI} - 100)/9)]^{(1/2)+(1/6)*[\exp(-\mathrm{GSI}/15)-\exp(-20/3)]} \tag{5}$$

For the inverse derivation, the perfect correlation (R^2 = 0.99995) can be used with a sigmoidal (logistic) function of the type:

$$\mathrm{GSI} = (A1 - A2)/[1 + (JP/X_o)p] + A2 \tag{6}$$

with

$$A1 = -12.198;\ A2 = 152.965;\ X_o = 0.191;\ p = 0.443. \quad \text{Then} \quad \mathrm{GSI} \approx 153 - 165/[1 + (JP/0.19)^{0.44}] \tag{7}$$

Based on such a correlation, a "robust" quantitative estimation of the GSI can be made, by defining the parameters concurrent to the evaluation of JP, i.e. the block volume (Vb) and the Joint Condition factor (jC). A graphic representation of the described correlation is presented in Fig. 2.

The sector I of the graph shown in Fig. 1 is derived from the above equations. The quantification of the Joint Condition Factor (jC) is based on published tables (see for example Palmstrom's web site www.rockmass.net, where a complete treatment of the RMi method can be found). Following the suggestion of Palmstrom (2000), some typical jC values are reported in the graph as well for a quick preliminary evaluation.

Finally, it should be noted that the use of the described (GRS) approach is not recommended in complex and heterogeneous rock masses, such as a flysch, where the specific charts proposed by Marinos and Hoek (2001) may be a more opportune reference for calculating the GSI.

2.2. Graph II: Estimation of rock mass strength

Graph II (lower left quadrant in Fig. 1) estimates the Rock mass strength (σ_{cm}) based on Rock Mass Fabric (GSI) and Intact rock strength (σ_c).