ICUSESS '92: 5th Int. Conference on Underground Space and Earth Sheltered. Structures. August 2--7, 1992

The use of rock mass classification systems in assessing the long term stability of underground openings.

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ABSTRACT: Long term stability of the limestone mines in the South of The Netherlands is assessed with the Q-system for rock-mass classification. Rock-mass classifications are calculated for different mines and mine areas. The predicted stand-up times up to 500 years seem to correlate very well with reality. One mine is assessed in more detail and a remarkable correlation exists between the Q-system values, span width and the degree of fracturing of the pillars. Using the Q-system for predicting future stability of the limestone mines leads to the conclusion that some mines are at the end of their lifetime and that collapse might be imminent.

1 INTRODUCTION

Limestone calcarenite and calcisiltite formations outcrop in the South of The Netherlands. The formations are from Maastrichtian age. The limestones have been mined for building material since Roman times and mining stopped around the 1950s. Irregular rooms and pillars have developed as the result of sawing blocks out of the rock. The spans of the rooms approximately range from 4 to 7 metre. Presently some mines are visited by tourists. Other areas are collapsed or are in a state that is not expected to be stable and where collapse is imminent.

A considerable amount of research has been done by the Delft University of Technology to establish stability criteria (Bekendam, 1990, Price, 1989, Steveninck, 1987, Vink, 1991). Laboratory experiments and case histories have shown that the limestones are susceptible to creep deformation (Bekendam, 1991). Some mines that have been stable for decades to centuries have deteriorated within a few years resulting in large scale collapses. An example is the collapse of a major part of the 'Heidegroeve' in 1988 (Price, 1989). All these research data have been used for assessing the stability and stand-up times according to the Q-system for rock-mass classification (Barton 1976). A preliminary stability analysis with the Q-system of the mines and mine pillars has been reported in 1990 (Hack, 1990). The data used then was rather incomplete and in particular the age of mine areas and pillars was not known in detail. Since then more surveying and research on data of the mines has been carried out and is used in this article.

2 ROCK-MASS CLASSIFICATION SYSTEMS

Rock-mass classification systems are empirical systems used for the estimation of rock-mass strength and behaviour. Rock-mass parameters as intact rock strength, discontinuity parameters (bedding, jointing, faulting), water pressures, etc. are quantified in empirical numbers. These numbers are used in a formula and result in a final rating that quantifies the rock-mass strength and related rock-mass parameters as un-supported stable tunnel span and stand-up time. Most systems also give recommendations for tunnel support.
The empirical numbers for rock-mass parameters and the formula are developed on hundreds of case histories and can therefore with a reasonable reliability be used to predict rock-mass parameters in other underground excavations. For a detailed description of rock-mass classification systems and their development is referred to the literature (Barton, 1976, Bieniawski, 1989, Laubscher, 1990).

3 ROCK-MASS PARAMETERS

The limestone layers of the Maastrichtian in the South of The Netherlands are fairly massive. Tectonic faults are infrequent and jointing is virtually absent. Extensive laboratory testing on block samples has been executed. UCS values approximately range between 1 and 4 [MPa] and Brazilian test tensile strength values range approximately from 0.1 to 1.2 [MPa].

4 Q-SYSTEM PARAMETERS

The so-called Q-factor is calculated using eq.1. This equation and the various parameters have empirically been established by Barton (Barton, 1976).

$$Q = \frac{RQD}{J_n} x \frac{J_r}{J_a} x \frac{J_w}{SRF} \qquad 1$$

RQD = *Rock Quality Designation* $\quad$ J_n = *Joint set number*

J_n = *Joint Roughness number* $\quad$ J_a = *Joint Alteration number*

J_w = *Joint Water reduction number* $\quad$ SRF = *Stress Reduction Factor*

The parameters in eq.1 have been evaluated for the limestone mines and values have been established as described below.

RQD (Rock Quality Designation)
The RQD is 100 % for the limestone layers as there are virtually no discontinuities as bedding or joint planes.

Jn (Joint set number)
For the same reason the Jn (joint set number) is set to a minimum value possible. However Barton recommends to multiply the Jn factor with 3 for intersections. The room and pillar mining method causes so many intersections that this is allowed for the mines. The Jn becomes therefore 0.75 * 3 = 2.25.

Jr & Ja (Joint Roughness number & Joint Alteration number)
Jr (joint roughness number) and Ja (joint alteration number) both describe the shear strength characteristics of a discontinuity. Discontinuities are absent and therefore also the Jr factor is set to the optimum value of 4. Ja is taken as 1.00 and not to the optimum value because the optimum value represents a discontinuity with tightly healed, hard, nonsoftening, impermeable filling; i.e., quartz or epidote. Thus a discontinuity filling that is of better quality than the surrounding rock. A value of 1 representing unaltered discontinuity walls is more appropriate for the limestone mines.

Jw = 1 (Joint Water reduction number)
The mines considered are all above ground water level and water inflow in the mines is minor.

SRF (Stress Reduction Factor)
The stress reduction factor depends either on the occurrence of weakness zones in the rock-mass, or on swelling or squeezing characteristics of the rock-mass or on the ratio of the major principal stress over compressive or over tensile strength of the intact rock material.
Weakness zones or shearzones occur only occasionally and are not expected to have a serious influence on the rock-mass stability. Also the rock material is not expected to squeeze or swell so that the SRF parameter is determined by the strength - stress ratios. Two approaches for calculating the strength - stress ratios have been used:

1 For a preliminary general assessment data from parts of the following mines have been used: 'Jezuieten', 'Heide', 'Geulhem' and 'Hoorensberg' mines (2). The SRF has been determined by calculating the ratio of the laboratory UCS compressive strength to the overburden pressure, and the laboratory Brazilian test tensile strength value to the overburden pressure. The ratio that resulted in the lowest SRF value has been used for calculating the Q value.

2 For a detailed assessment of different pillars in the 'Geulhem' mine (3) the SRF value is based on the ratio of UCS strength over the stress in the pillar (Steveninck, 1987, Vink, 1991). The stress in the pillars is calculated according the tributary area method. Eq.1 calculates the stress on the pillar (Goodman, 1980).

$$\sigma_{pillar} = \frac{A_{trib} * W_{ow}}{A_{pillar}} \qquad 2$$

$$\sigma_{pillar} = stress\ on\ pillar$$
$$W_{OW} = overburding\ pressure$$
$$A_{trib} = the\ tributary\ area$$
$$A_{pillar} = the\ gross\ area\ of\ the\ pillar$$

The ratio of compressive strength over the stress according eq.1 is calculated and the corresponding SRF value is determined according figure 1. The relation between Sc/S1 and SRF is slightly modified with respect to the original graph published by Barton (Barton, 1976) because a strange dip at a Sc/S1 = 10 occurs in the original graph.

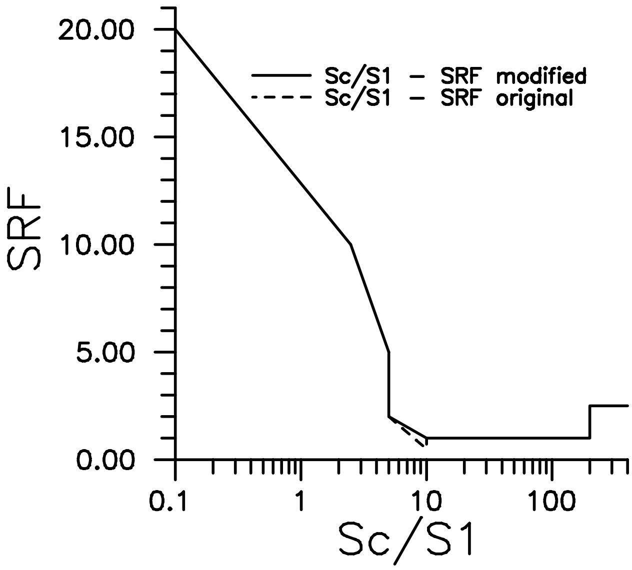

Figure 1: Sc/S1 - SRF relation

5 SPAN WIDTH

In general span width ranges between 4 and 7 metre for the different mines. The span width in the 'Geulhem' mine is rather constant at approximately 4.5 metre.

6 STAND-UP TIMES

Stand-up times have been achieved from historical sources and from dates written on the walls in the mines. Many stand-up times are rather minimum stand-up times because the dates do not necessarily reflect the building year of the mine.

7 PILLAR CONDITION

Pillars in the mines have been surveyed and a classification for the condition of the pillars has been established by various authors (Bekendam, 1991, Price, 1988, Steveninck, 1987). Pillars are divided in 4 classes depending on the amount of visual damage and fracturing. The classes are listed in table 1.

Table 1: Pillar classification.

Class:	Description of pillar:	Condition:
1	No cracks	very good
2	Cracks and/or spalling only in the top or in the bottom of the pillar	good
3	Cracks and/or spalling going completely from top to bottom of the pillar	poor
4	One or more pillar sides parted from the central rock-mass of the pillar (wedge geometry)	very poor

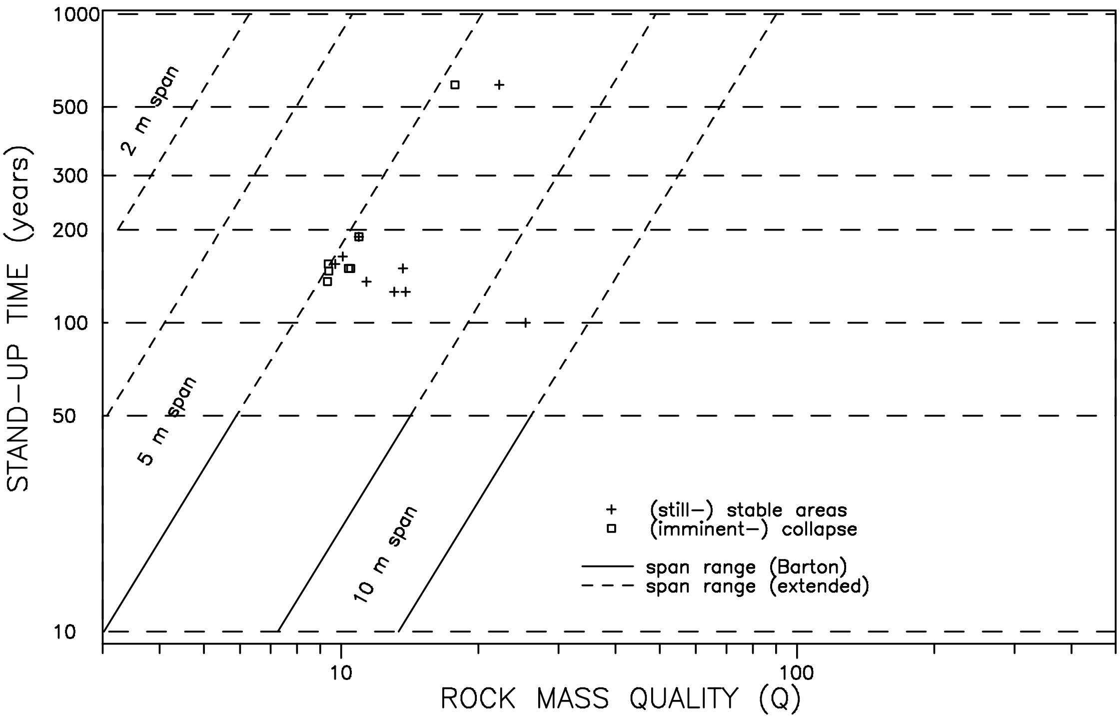

Figure 2: Overall stability of parts of several mines in the South of The Netherlands.

8 RESULTS

Figure 2 shows clearly that mine areas that are collapsed or where collapse is imminent are on the boundary of the extended 5 m span range. This is in agreement with the actual span ranges of 4 to 7 m. Most other points that are visually described as stable, are further away from the extended 5 m span range. Only 3 of the stable area points are near this boundary. Although visually no damage has been established for these later points it might be that these areas are also in a nearly collapsing state.

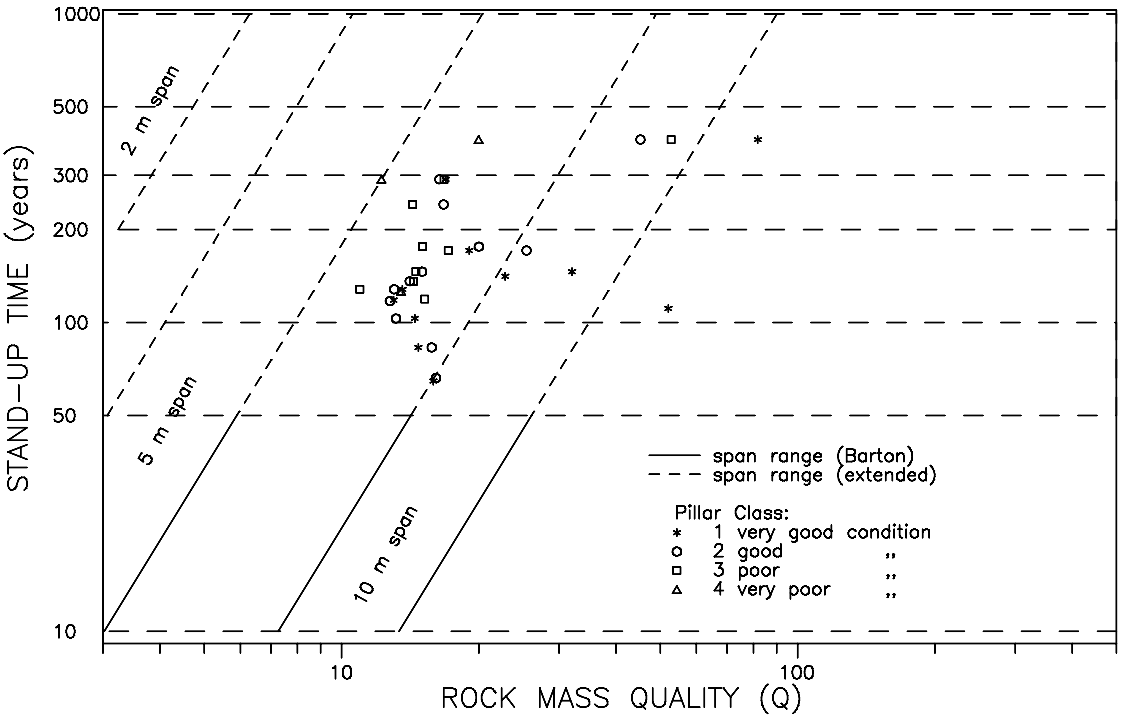

Figure 3: Individual pillar stability in the 'Geulhem' mine.

Figure 3 shows the Q-values against stand-up time of 331 individual pillars averaged according Q-value and class in the 'Geulhem' mine. The pillars with a poorer condition are clearly more to the left and thus nearer to the extended 5 m span range than pillars that are in a better condition. None of the pillars included in 3 is in an actually collapsed area. All pillars are accessible and could be visually described and surveyed. Pillars with a poorer condition than class 4 are expected to have (partially-) collapsed and are in areas not accessible.

9 CONCLUSIONS

1 It is of interest that the extension of the stand-up times, which have been predicted by Barton only up to 50 years, seems to reflect with reasonable accuracy the actual stand-up times up to 200 years and probably up to 600 years.

2 The fact that collapsed areas and failed or heavily damaged pillars are in accordance with the extended Barton stand-up time predictions might implicate that the graphs can be used for predictions for future stability of mines and mine areas that now are still stable. This would lead to the conclusion that a considerable amount of mines and mine areas in the South of The Netherlands might be at the end of their life time and that (partial-) collapse will occur in the foreseeable future.

Investigations and research on the above is still ongoing and further results will be reported.

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