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Improving teaching methods of rock mass classification parameters

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ABSTRACT: To promote knowledge in rock mass classification methods, a short course was arranged in research tunnels beneath Aalto University in Espoo, Finland. After the course, the participants had a short (45+45 min) hands-on tunnel mapping exercise where they logged 12 core boxes and one 10 m tunnel wall section. The attendees were asked to submit their mapping sheets for a post-study. The objective of the study was to discover which parameters show most scatter and to develop suggestions to improve the teaching methods. Statistical analysis of the data was carried out and *RQD* parameter was analyzed in more detail as it had the largest amount of data. Insufficient logging time may be one of the causes for the lack of data for other parameters. Significant scatter was observed in the *RQD* parameter and the comparison between inexperienced and experienced mappers show no clear difference. The teaching arrangements and problems faced are stated and recommendations on how to improve the situation are presented.

1 INTRODUCTION

1.1 Background

Classification or characterization systems are often used in early stages of rock engineering or mining projects to categorize the quality of the rock mass. There are several methods available, which emphasize different parameters and none of them covers all possible situations and parameters. The types of rock in Finland are fairly uniform and stronger than in most European countries because they are formed in slow solidification and crystallization of magma, a product of the volcanic activity, or the hardening and petrification of loose soil materials. For such favorable bedrock conditions, the Tunnelling Quality Index *Q* (Barton et al. 1974) is a suitable method. The method is widely used in the Fennoscandian countries (Norway, Sweden and Finland) and improving and unifying the teaching methods could have favorable impact for the industry.

A *Q*-system Course was carried out at the Aalto University (Finland) during spring 2013 to study and use the method. Dr. Nick Barton gave two days of lectures and a short hands-on exercise was arranged on the third day. The 100 attendees were students from Aalto University and other nordic universities as well as industry representatives and experts. The aim was to give strong theoretical background for the method and its applications as well as to provide a short practical experience in realistic conditions.

The attendees were asked to submit their mapping sheets for a post-study.

The origin of this study is based on an observed variation in the logging results presented in Edelbro et al. (2006). A round robin test, applying characterization systems for three specific and well described cases was used and the results indicated difficulties in selecting parameters; poorly described parameters, major influence of parameters related to the joint shear strength as well as over and underestimation of the strength. Hence a precise estimation of the rock mass quality could not be expected. A preliminary mapping experiment preceded this study in spring 2012, where the Edelbro observations were supported by observations from student behavior during mapping exercises.

The *Q*-system Course was arranged in spring 2013 where attendees could submit their logging sheets on a voluntary basis. There were 65 sheets which 64 of them were used, and 24 of these sheets were made by participants with at least one year of experience.

1.2 Objectives

The main objective of this study was to improve the teaching method for the *Q*-system parameters. To this end, the teaching process with merits and flaws in described and suggestion for improvement are

presented. The secondary objective was to study the influence of experience. This was enabled by asking the amount of logging experience in the mapping sheet. The participants were split into two categories: less than one year of experience (inexperienced) and more than one year of experience (experienced) and the results were considered in a combined data set, inexperienced and experienced data sets to detect differences.

2 THE Q -SYSTEM

To determine the rock mass characteristics and tunnel support requirements, Barton et al. (1974) proposed the Tunnelling Quality Index (Q). The Q value gives an estimation of the type of permanent support recommended. It provides a number between 0.001 and 1000 and it is defined by:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}, \quad (1)$$

where RQD = Rock Quality Designation; J_n = Joint set number; J_r = Joint roughness number; J_a = Joint alteration number; J_w = Joint water reduction factor; and SRF = Stress reduction factor.

In order to detect the variation of the Q -parameters, the Q -Histogram logging was used. The method can be used on surface, on core or in a tunnel section. In this study, the core logging and the tunnel section mapping were used. According to what kind of logging was used, there will be changes in the logging procedure and these changes must be stated.

Logging sheet provided by Barton (2002) is used to gather all the information from the logging. The sheet is divided in six different tables for each of the parameters in the Q -system. The user of the logging sheet marks one tick per observation in the boxes of the tables and the observations are then used to draw the parameter histograms which then produce the Q -histogram.

When drill cores are used, the core logging is straightforward: there is no ambiguity in selecting the location of the skyline, and it needs, at least, one observation per row. It is possible to increase the amount of observations to represent changes in the core observations. Most parameters can be analyzed according to the Q -system method. However, there are some items to consider explained in Norwegian Geotechnical Institute (2003):

- The scale of the joint roughness is not so large, so the coefficient J_r will be difficult to analyze.
- The coefficient J_a will be difficult as water is used to flush the holes during drilling and it can remove the filling material of joints.

- The drilling direction will bias the RQD and J_n parameters.
- SRF estimation may be possible in massive rock if stress measurements are carried out in the borehole.

In the Q -system Course, tunnel mapping works a bit different, because the amount of observations chosen will change according to what parameter was analyzed. First of all, the tunnel has to be divided in sections. The meters of each section will be decided according to the variation of the rock quality of the wall, so the variation between sections cannot be higher than one rock class (Norwegian Geotechnical Institute, 1997). The first step of the logging is to visualize a vertical skyline from the roof to the floor of the wall and make as many observations as needed per skyline. It is especially important to describe the weakness zones and more observations are in order in the vicinity of these phenomena.

3 THE Q -SYSTEM SHORT COURSE

The Q -system was introduced in the course, as well as some practical applications and selected cases studies. The course was designed for undergraduate students in Geoengineering at Aalto University. The course was also open for people from the industry with geological or rock engineering background. In other words, the level of knowledge and experience in applied earth sciences was very different among the participants. The first two days were covered of lectures given by Dr. Nick Barton, and the third day, the participants had a chance to take part in a tunnel mapping and core logging exercise in the presence of Barton and some Aalto staff. The practical field exercises were carried out in the Research Tunnel beneath the Otaniemi campus in Espoo.

During the third day, once the first group arrived in the Research Tunnel and before start the mapping/logging exercises, they were told which tools were at their disposal:

- Logging sheet: one side for log the core boxes and the other side for tunnel sections
- Q -tables with classifications
- Roughness profiles for Joint Roughness Coefficient (JRC)
- Profilometer (Barton's comb)

Half of the group proceeded to log the core boxes and the other half proceeded to map the tunnel wall section. They had 45 minutes for each exercise and then switched to the other task for another 45 minutes (90 min in total).

3.1 Core logging

In the core logging room there were twelve core boxes from three different sites of southern Finland.

Once the participants arrived in the logging room, the instructor made a short explanation about how to log the core boxes and how to fill the sheet. The artificial (man-made) fractures were noted on the sides of the core boxes and the importance to differentiate a natural rock fracture and a man-made/artificial fracture was explained. The participants worked alone with one core box at a time. After they finished logging RQD for a core box, they moved to the next free one until they ran out of time. When they finished logging all boxes, they could wait for the switch or continue logging rest of the parameters if they were experienced enough to do it (see the associated difficulties listed in Chapter 2).

3.2 Tunnel Mapping

The west wall connecting the civil defense shelter to the campus housing area was used. The wall was divided in sections of 10 meters each from 0 meters to 80 meters (green chainage markings in Figure 1).

Once the participants were in the tunnel, the Aalto staff explained how to fill the sheet and how to imagine five windows, see yellow line in Figure 1, per section in order to map the RQD. In each window they would create an imaginary skyline (red line) and divide it in three one meter long partitions. The staff did not specify explicitly where to make the skyline, so the participants could create it on the middle, on the left or on the right of the window.



Figure 1. Chainage 00-10 meters with windows (yellow) and skylines (red).

The amount of observations per parameter that every participant had to do was:

- RQD: 3 per skyline, 15 data points in total.
- J_n : 1 per skyline, 5 data points in total.
- J_r : 1 per section, 1 data point in total. *
- J_a : 1 per section, 1 data point in total. *
- *) The worst combination of J_r/J_a (from same joint) should be used.
- J_w : 1 per section, 1 data point in total.
- SRF: 1-5 per section, from 1-5 data points in total. The amount of observations needed depends on presence of weakness zones.

3.3 Statistical analysis

The statistical analysis begins with creation of the Q-Histograms and then proceeds with calculation of statistical parameters from the RQD. Only the RQD parameter could be analyzed as the rest of parameters had too low submission count. The analysis proceeded in steps:

1. Digitalize the data of the sheets to a worksheet program.
2. Backup the original data and continue with a working copy.
3. Identify the data that is corrupted. First, create a new worksheet in order to separate the participants in team works already created during the logging and mapping of the tunnel, and thus find if there is any common information between the sheets of the participants. Then, identify the data of the participants that doesn't make sense, for example, when the data is outrageously different compared to the rest of participants.
4. Normalize the data considering the amount of the observations per box or section.
5. Compile graphs of the boxes and sections considering the observations and the RQD categories, and then add the average (red line) of all the participants in each graph.
6. Draw the histogram of each graph.
7. Create the box plot of the boxes and the tunnel sections considering the observations per row.
8. Calculate the RQD typical range (minimum and maximum of the values), RQD mean (arithmetic average) and RQD mode (most frequent number).
9. Create tables with a summary of the most important information about the core boxes and tunnel sections.
10. Analyze these tables to discover which boxes and sections are the most representative and make conclusions.
11. Divide the data in to non-experience and experience participants.
12. Start from the step number 4 and make the same analysis with non-experience and experience participants.

4 CORE LOGGING RESULTS AND DISCUSSION

The logged results match visually to the core box photos when the RQD is high. Figure 2 shows a core box photograph of a core segment where the quality of the rock is predicted as good according to the

RQD-Histogram in Figure 3. However, there are some pieces of drill core missed in all the rows, most probably that's the reason of the tail from the Figure 3.



Figure 2. Photo of the core box L-3.

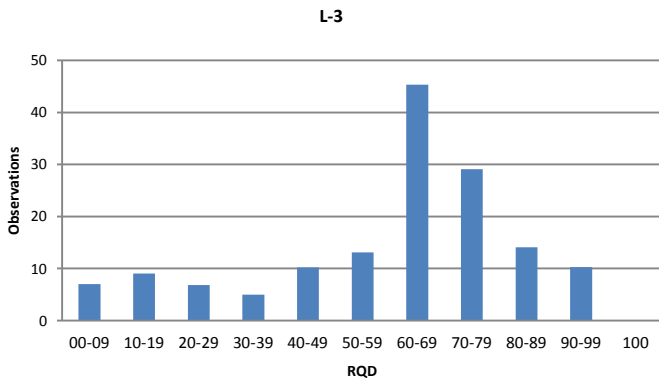


Figure 3. *RQD*-Histogram from the core box L-3, mapping made by 25 participants.

Most of the boxes show a wide range of *RQD* values with one or more peaks. Because the participants map one box on one row, it can happen if there isn't any similarity between the rock core rows.

5 TUNNEL MAPPING RESULTS AND DISCUSSION

Chainage 10-20 meters is shown in Figure 4. The section doesn't present too many joints, but on the left of the picture there is a weakness zone. In general the rock quality was predicted as good according to the *RQD*-Histogram in Figure 5.



Figure 4. Photo of the 10-20 tunnel section.

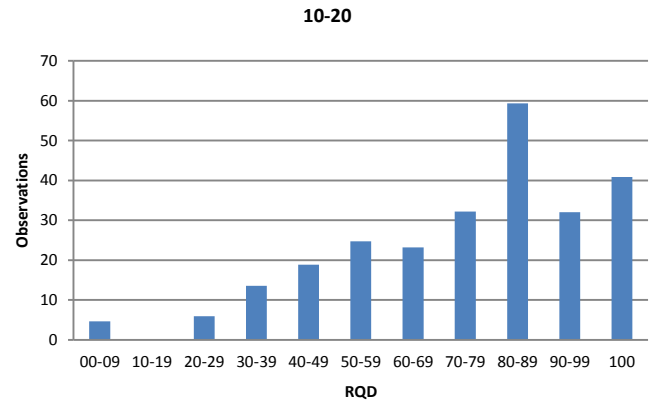


Figure 5. *RQD*-Histogram from the 10-20 tunnel section, mapping made by 17 participants.

Comparing Figure 4 and Figure 5 it is possible to see that the logged values are relatively consistent. The statistical parameters (mean, median and mode) are close to each other but the histogram doesn't show a normal distribution. The mean and median are exactly the same in almost all the sections. The *RQD* ranges are from 5 to 100, so they are wide in all the studied tunnel sections. This can be caused by the arbitrary selection of the 10 meter mapping window instead of following the recommendation in Norwegian Geotechnical Institute (1997).

There were not a lot of participants mapping the sections, so it is quite difficult to produce reliable results. Some sections have only eight or three participants. The first three sections have more participants as they were situated at the beginning of the tunnel and mapped regardless of group size.

An important remark is that from the tunnel there are more parameters available than from the cores, but as the *RQD* results are not consistent and it is the most reliable parameter based on submission count, most probably the rest of the parameters are going to be same or lower reliability.

The results from the tunnel mapping show a wide scatter in the results. One possible reason is that time given (45 min) to make the mapping was not sufficient for meticulous work.

6 INFLUENCE OF EXPERIENCE RESULTS AND DISCUSSION

The number of participants for the core box L-3 was 11 with experience and 14 with non-experience. In Figure 6 *RQD*-Histograms for the experienced and non-experienced participants is shown.

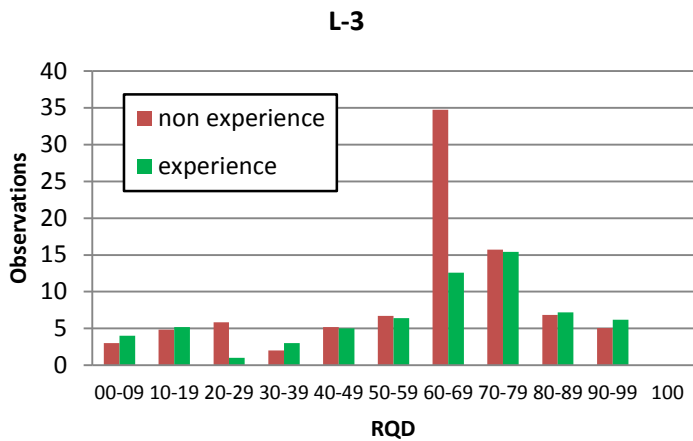


Figure 6. *RQD*-Histograms from experience and non-experience participants from L-3.

The amount of participants for the 10-20 tunnel section mapping was 7 with experience and 10 with non-experience. The observations from the non-experience appear more scattered than the ones from the experience.

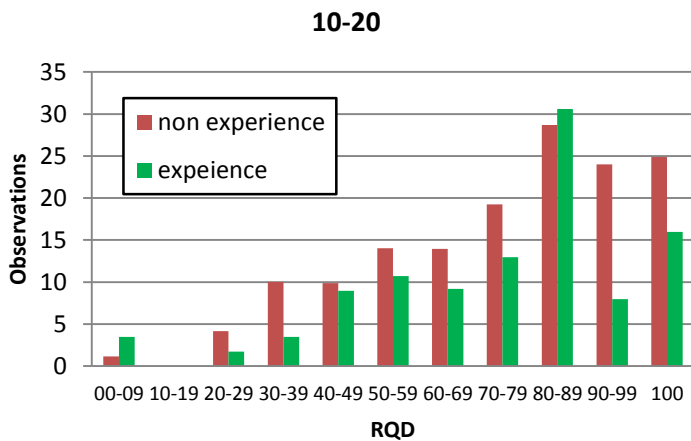


Figure 7. *RQD*-Histograms from experience and non-experience participants from the 10-20 section.

The comparison shows that there isn't a clear difference between the experience and non-experience participants. The *RQD*-histograms of the more experienced participants appear to match a bit better the rock quality than the non-experienced.

7 CONCLUSIONS

7.1 Combined conclusions

Based on this study, core logging is easier to carry out and produces more consistent results than tunnel wall mapping. The speed of the core logging is much higher than the tunnel mapping. The *RQD*-Histograms of the core boxes are more representative and reliable than the ones from the tunnel section. Mapping tunnel wall requires more time to carry out meticulously.

When the *RQD* is high or there is clear contrast of rock quality between rows of the same box, the results appear consistent with the core box photographs. Generally a wide scatter was detected in almost all of the *RQD* results. Comparison between inexperienced and experienced mappers shows little improvement.

7.2 Teaching suggestions

Based on the observations, the following suggestions are given to improve the teaching method:

- Explain how to fill the sheet with examples corresponding to cases.
- Explain in detail how to analyze each of the *Q*-parameters. Show different parameter values with example pictures.
- The logging parameters must be strictly enforced to provide normalized raw data:
 - Mark the location of the skylines
 - State amount of observations
 - Control the amount of persons.
- Allocate more time to enable learning.

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