A Method of Recording and Presenting Rock Mechanical Data

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ABSTRACT

The engineering geological and the rock mechanical data must be systematically recorded and properly arranged for presentation purposes. The method presented in this paper requires the recording of key geotechnical parameters in a logging chart containing histograms. Data mapped from different sites at a project can then be manuplated/interpreted and combined through a PC based spreadsheet to give a condensed description of a larger area or the whole project site. The applications of the geotechnical logging chart at Underground Power House of Sardar Sarovar Multipurpose in India and Underground Olympic Stadium in Norway have been presented in this paper.

Key Words: Geotechnical logging chart, Q-system, engineering geological and rock mechanical data.

1. INTRODUCTION

Engineering geological data mapped from the surface, underground or through drillholes is important for planning and designing of structures in rock mass. Such data must be systematically recorded and properly arranged for presentation purposes. This data is also necessary for numerical analysis and modelling studies. It becomes extremely difficult for recording, storing and manuplating key engineering geological and rock mechanical parameters obtained from field mapping inside drifts, tunnels, underground excavations and drillhole core logging. In order to cope up with the huge amount of data collected from a site or through drill core logging, a special method has been developed at the Norwegian Geotechnical Institute (NGI), Norway for illustrating the data so that it may be easily recorded and used whenever required. In this method, engineering data is recorded on a geotechnical logging chart displaying histograms which are subsequently punched into a PC based spreadsheet (lotus) which allows the data to be combined or manuplated according to the user's wishes.

The mapping of rock mass is used in rock mechanical studies to determine the special distribution of joints, discontinuities and faults that divide the rock mass into its blocks. The geotechnical field mapping is generally conducted at two levels. The first level is for quick reference, and it shows a brief summary of all the parameters that are considered to be of importance while performing geotechnical field mapping. Extensive use is made of the geotechnical logging chart that forms the basis for the presentation of field mapping results. The second level is for the description of each parameter in more detail, with procedures to be followed in the evaluation of each parameter. The application of geotechnical logging chart at both the levels is useful.

The present paper describes the method of recording the key geotechnical parameters including the data required for rock mass classification of Q-System developed by Barton et al. (1974) at NGI, Norway. These parameters are a key to the process of rock mass behaviour prediction. The method is explained through engineering geological mapping performed at the sites of Norway's underground olympic stadium and in the underground power house cavern at Sardar Sarovar Project in Gujarat, India.

2. Q-SYSTEM

Rock mass classification systems, which form the backbone of the design methods by empirical approach, provide guidelines for the estimation of support pressure and tunnel reinforcement. The Q-system was developed by Barton et al. (1974) of the Norwegian Geotechnical Institute (NGI) and it was further updated by Grimstad and Barton (1993). The application of Q-system for Norwegian Method of Tunnelling (NMT) is presented by Barton et al. (1993) and use of NMT principles in predicting the performance of underground power house at Nathpa Jhakri Project in India was presented by Chryssanthakis et al. (1996). The Q-system is the most widely used classification system based on a numerical assessment of the rock mass quality (Q) using six different parameters which comprise the following equation for rock mass quality:

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

where,

RQD = rock quality designation (Deere et al., 1967),
J_n = joint set number,
J_r = joint roughness number (of least favourable discontinuity or joint set),
J_a = joint alteration (filling) number,
J_w = joint water reduction factor, and
SRF = stress reduction factor.

The above six parameters for evaluating rock mass quality, each of which has a rating of importance (Barton et al., 1974), can be estimated from geological mapping inside adit/ exploration drift/ tunnel, surface mapping and from core logging and can be verified during excavation. The rock mass quality, Q may be considered as a function of only three parameters which are crude measures of the following:

1. Block size (RQD / J_n),
2. Minimum inter-block shear strength (J_r / J_a),
3. Active stress (J_w / SRF).

The range of possible Q values varying from 0.001 to 1000 encompasses the whole spectrum of rock mass qualities form soil-like heavy squeezing ground (Q=0.001) up to sound unjointed rock mass (Q=1000).

3. GEOTECHNICAL LOGGING CHART

The geotechnical logging chart highlighted in this paper is explained through engineering geological mapping carried out inside the underground excavations. Field mapping is used in geotechnical studies to determine the spacial distribution and properties of joints, discontinuities and faults that divide the rock mass into its component blocks. The objective of field mapping is to obtain structural, strength and deformability related data as illustrated by Barton (1983) and Singh and Bhasin (1996). The data interpreted from the field mapping can be used to supplement and extrapolate core logging data in the same rock. A drill core or drillhole is more or less a line sample of the rock mass. It provides convenient samples of joints and faults material for testing and characterization, but it is a poor sampler of the three dimensional properties of the rock mass. Field mapping is a means of extrapolating structural data and often gives clear indication of the various structural domains within the rock mass.

4. ROCK MASS QUALITY

The rock mass classification system (Q-system developed by Barton et al., 1974) using a new method of recording and presenting engineering geological data has been illustrated by using two case studies.

In the first case study, the example of underground power house of Sardar Sarovar Project in India was considered. 10 observations of each parameter required for evaluating rock mass rating were taken in an area of approximately 200 m^2 during the benching operations near the upstream wall of the underground power house cavern. The bedrock within the area around the underground power house cavern consists of subhorizontal lava flows of basalt with intrusive dolerite sills and lenses of agglomerate.

Histograms for the above mentioned six parameters of Q-System of rock mass classification are shown in Fig. 1 with the weathering grade (W) included as an extra qualifying term. Figure 1 shows rectangular graduated areas for making numerous individual observations of various Q-system parameters. The frequency of observation i.e. each rectangle in the histogram corresponds to one exposer.

While filling the rectangular areas in the histogram, efforts are made to estimate the approximate percentages of the various qualities observed e.g. in the case of Q-characterization in Fig. 1, approximately 60% of the area considered is evaluated as having a RQD value between 70-90, 20% between 60-70 and the rest 20% between 40-60. Similar procedures are adopted for evaluating the joint parameters J_n, J_r, J_a and J_w while the factor SRF is evaluated from in-situ stress conditions. In this case, medium stress is considered i.e. SRF=1. The stress reduction factor (SRF) is evaluated correctly by using the data in-situ stress measurement and unconfined compressive strength. The rating of SRF is determined from the ratio of uniaxial compressive strength and major principal stress.

The most typical rock quality visible during the benching operations at the underground powerhouse cavern as presented in Fig. 1 was calculated. The examples of calculating the best, the poorest and weighted average typical values of rock mass quality, Q have been illustrated in the following equations:

Typical the best quality

$$Q_{\max} = \frac{90}{4} x \frac{3}{2} x \frac{1}{1} = 34 \qquad (2)$$

Typical the poorest quality

$$Q_{\min} = \frac{60}{12} x \frac{1.5}{4.0} x \frac{0.66}{1.00} = 1.2 \qquad (3)$$

Typical the weighted average quality

$$Q_{average} = \frac{71}{7.7} x \frac{2.2}{2.6} x \frac{0.864}{1.000} = 6.8 \qquad (4)$$

The weighted average of RQD as evaluated from the data stored in Fig. 1 is shown below:

RQD = (1x45 + 1x55 + 2x65 + 3x75 + 3x85) / 10 = 71 %

Similar procedures are adopted for other parameters from the histograms for evaluating typical values of rock mass quality.

In the second case study, the example considered the mapping work carried out during the construction of underground stadium for the 1994 winter olympic in Norway. The Q-system parameters along with other important engineering geological data form a set of information required for designing and modelling of underground structures. This set of information is shown on a geotechnical logging chart in Fig. 2 for the construction of underground cavern in Norway. The Q-system parameters occupy left hand side of Fig. 2.

In the histograms drawn for each parameter, values plotted on the right hand side of the chart are favourable for good stability, while values plotted more on the left hand side imply poor stability.

This chart can be arranged in a special manner for convenience in field mapping, in core logging, and in subsequent use of the information. In the middle section of the chart, there are histograms for joint frequency (F), joint spacing (S), joint roughness coefficient (JRC), joint wall compressive strength (JCS), permeability (k), rock strength and rock stress. On the right hand side of the chart, there are histograms showing Schmidt hammer readings (R, r), volumetric joint count (Jv), joint length (L), joint roughness amplitude (a/l), residual friction angle and joint orientation.

This method of recording six Q-system parameters and other geotechnical information during field work for small or large areas has been found very useful. Incorporating all the information in a PC based spreadsheet (lotus) makes it possible to see the variation in the different parameters through the underground cavern. Hence, data from different areas may be manuplated and combined. The geotechnical chart contains information for setting up input data files for numerical modelling of critical sections of the cavern.

5. ENGINEERING PARAMETERS

A brief description of all the parameters that are considered to be of importance while performing field mapping and core drilling are given in this section. These parameters have been recorded in the geotechnical logging chart during the construction of the world's largest man made rock cavern for public use in Norway (Bhasin and Loset, 1992).

The rock in the cavern area is a red and grey jointed gneiss of Precambrian age. Due to tectonic effects, the rock has developed a network of micro joints and small zones with a few centimeters of clay fillings. The geological investigations during the construction process involved detailed joint surveys in the excavated portions of the cavern and provided data on joint orientations, conditions and spacings of joints. Measurements of strike and dip of the main discontinuities were made through out the cavern.

The rock mechanical parameters obtained during the construction process from 35 areas which together make up the majority of the upper part of the olympic cavern are shown in Fig. 2. The mean RQD value between 60 and 70 reflects a rather small joint spacing and several joint sets. The mean J_n is about 9 which indicates that there are three joint sets. The joints have a $J_r = 2\text{-}3$ which means smooth to rough, undulating joints. Most of the joints have no filling, $J_a = 1$. But in a few joints , a filling of clay or silt/sand is found, $J_a = 4\text{-}6$. There has not been any seepage problems in the hall and the stress condition seem to be very favourable, therefore $J_w = 1$ and $SRF = 1$ are representative. Together these parameter values produce a mean Q-value of 9.4 (fair rock conditions) and a typical Q-range of 1-30 (poor to good rock conditions) as shown in Fig. 2.

The jointing is rather irregular but usually three sets of joints are found. Set 1 are joint along the foliation in the gneiss, striking NW-SE with a dip of 50^0 towards SW. Joint set 2 has strike in a NE-SW direction and dips 40-70^0 towards NW. Joint set 3 strikes in a N-S direction and usually with a steep dip towards the E as shown in the stereo diagram of Fig. 2. The foliation joints in the stereo diagram are represented by triangles.

Parameters concerning the joints are also shown in Fig. 2. Data for two joint sets (A and B) are given here. Where Set A is considered as the most unfavorable for the stability of the cavern due to its penetrative property and persistence. The foliation joints are considered to be the most unfavorable and therefore correspond to Set A in Fig. 2. Joint Set B corresponds to either Set 2 or Set 3 depending on the development and persistence of these joint sets in different areas of the cavern.

Joint spacing, S(m), is usually 0.2m, whereas joint length, L(m), of 2-5m are the most usual. Some major joints cut through the whole cavern.

Joint roughness coefficient (JRC) is calculated by means of joint roughness amplitude measurements (a/l) which are obtained for two lengths 0.1 and 0.5m. The mean JRC value is between 6 and 8.

Joint compressive strength (JCS) is obtained by means of Schimdt hammer readings. The mean JCS value is between 50 and 100 MPa. Joint frequency, F per metre is obtained from line sample of the rock mass. Permeability, K (m/s) can be estimated based on experience but hydraulic measurements in the drillhole can provide this information. Major principal stress (σ_1) must preferably be measured in-situ by using overcoring/hydraulic fracturing methos or be estimated based on experience prior to reliable data on the distribution or orientation of the major principal stress with depth/lithology. Unconfined compressive strength (σ_c) is determined in the laboratory or can be estimated from experience during field mapping (Stacey and Page, 1986). Residual friction angle can be crudely estimated in the field based on the experience (Barton, 1993), or directly calculated by using smooth planer surfaces of the rock and Schmidt- hammer rebound tests on natural and unweathered surfaces (Barton and Chaubey, 1977).

6. CONCLUSIONS

This method of recording six Q-system rock mass parameters and other geotechnical information during field work for small or large areas has been found very useful. Incorporating all the information in a PC based spreadsheet (lotus) makes it possible to see the variation in the different parameters through the underground cavern. Hence, data from different areas may be interpreted and combined according to the need of user. The geotechnical chart contains information for setting up input data files for numerical modelling of critical sections of the cavern.

This method of recording and presenting rock mechanical and engineering geological data is presently being used extensively for core logging, surface mapping and site characterization in the design and planning of underground excavations and tunnelling.

7. REFERENCES

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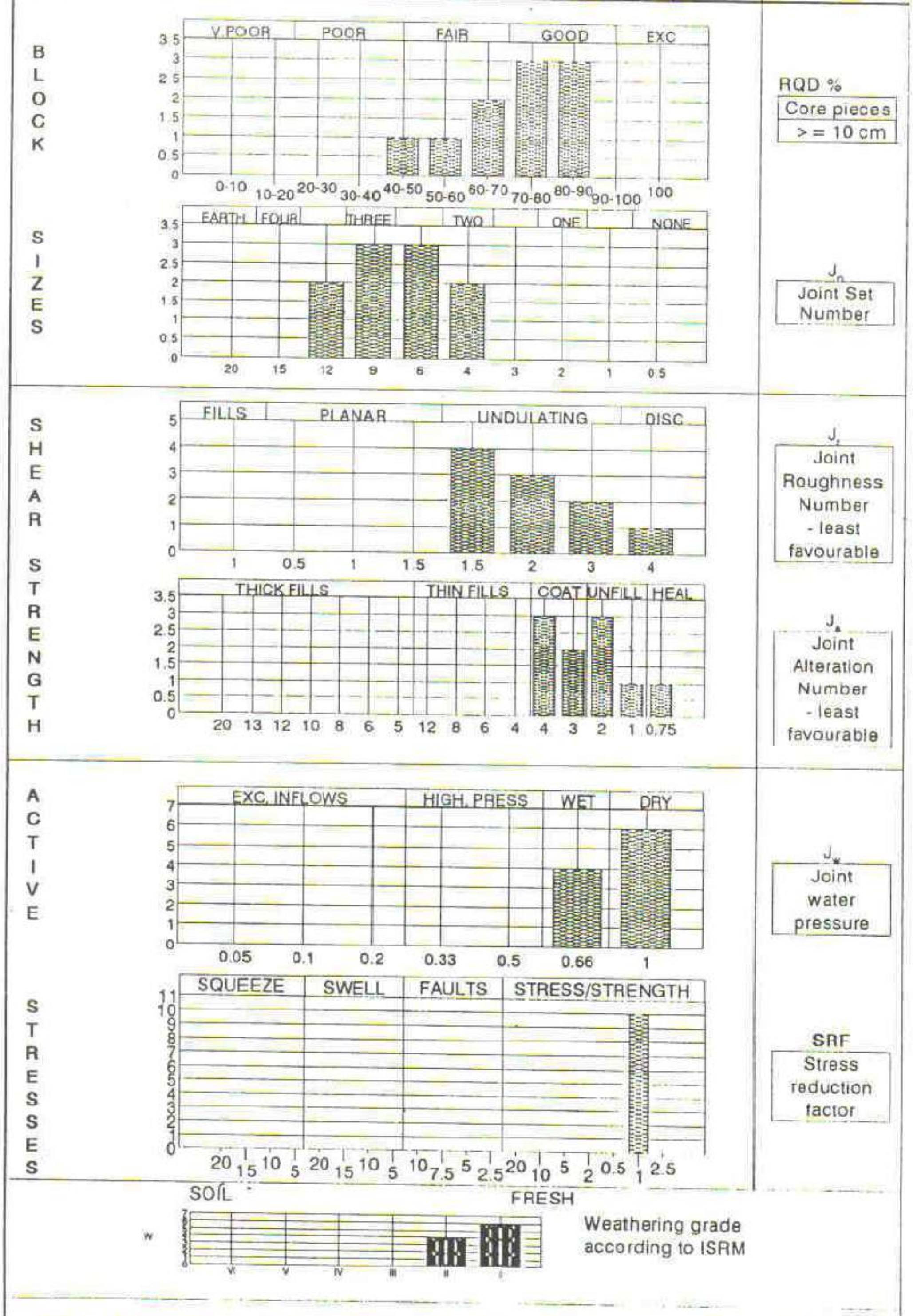
Q-VALUES:	(RQD /	J_n) *	(J_r /	J_a) *	(J_w /	SRF) =	Q	Benching Operations
Q(typical min) =	60.0 /	12.0 ·	1.5 /	4.0 *	0.66 /	1.0 =	1.237	
Q(typical max) =	90.0 /	4.0 ·	3.0 /	2.0 *	1 /	1.0 =	33.75	
Q(mean values) =	71.0 /	7.7 ·	2.2 /	2.6 *	0.864 /	1.0 =	6.806	



g. 1. Geotechnical logging of Q-system data of Underground Powerhouse at Sardar Sarovar Project, Gujarat, India

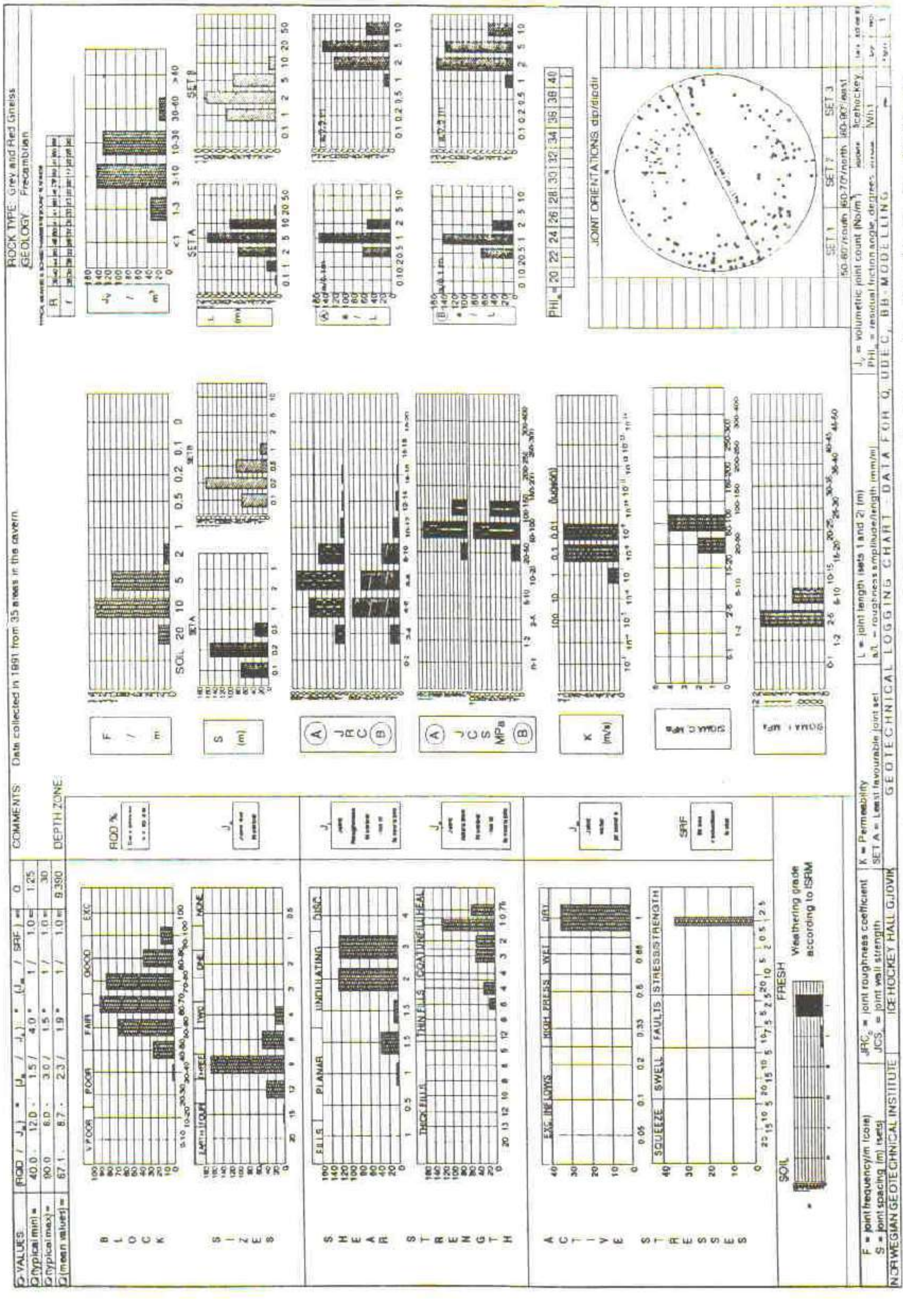


Fig. 2. Geotechnical logging of Q-system data of Underground Olympic Stadium in Norway