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RQD Range and the Threshold Value

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ABSTRACT. The RQD is the easiest method of calculating the desingation of the rock masses for design purposes. The threshold value of 100mm is used so far to calculate RQD, with no scientific or physical basis for choosing this value. If the RQD calculation is based on this value it could give an ambiguous evaluation of the actual RQD of the rock mass in concern, and different threshold values could lead to different RQD's. In this paper, various threshold values were chosen from 10mm to 100mm to calculate the effect of RQD using a written computer program utilizing Monte Carlo method. The criterion used in the assessment of threshold value is its change with the RQD range which is defined as the difference between maximum and minimum ROD values that occur during a simulation of RQD by Monte Carlo technique. The result appears as an inverse parabolic relationship between RQD range difference and the threshold value. This research recommends use of a threshold value between 10mm to 40mm to calculate the actual RQD of the rock mass which lead to a minimum expected error.

Introduction

The concept of quantitative description of discontinuities in rock masses is the essential information adequate for the basic engineering design in a rock mass. Rock Quality Designation (RQD) is such a description (Deere 1964 and ISRM 1979). Any value of RQD have long been recognised to be distributed evenly throughout the rock mass. Priest and Hudson (1981) expressed RQD as a function of the frequency of intact length distribution along a scan line. Palmstrom (1982, 1985) obtained RQD from volumetric joint count and later Kazi and Şen (1985) obtained RQD not influenced by number of observations.

Distribution of the discontinuity along a scan line was found to follow a log normal distribution by Steffen (1975); Bridges (1975); Barton (1977) and Şen (1984) while Priest and Hudson (1976) and Wallis and King (1980) found that it follows a negative exponential distribution. The distribution of discontinuity spacing along short scan lines was modeled by negative exponential and log-normal probability density functions by Şen and Kazi (1984).

The purpose of the research is to use Monte Carlo method to calculate the range of RQD which greatly influences the design engineer decision in various aspects of rock mass evaluation. However, the RQD value is, so far, calculated on the basis of threshold value of 100mm which gives an ambiguous estimation of the actual RQD; and consequently there might appears a significant source of error in the engineer's decision. Furthermore, the influence of various threshold values on the actual RQD of the rock mass is documented quantitatively in the form of charts and threshold value(s) are recommended for proper RQD calculations.

Rock Mass Characteristics

Simulation studies were first initiated by Goodman and Smith (1980). However, the numerical simulation of discontinuity distribution within the rock mass went into a recent development by Şen (1990) who used Monte Carlo method by which the engineer could recognise the maximum and minimum RQD values representing the rock mass along a scan line. This numerical technique enables the design engineer to estimate how much percent of low quality rock mass could be present within the whole (high quality) rock mass. Application of this concept is practiced by Sadagah (1989), Sadagah *et al.* (1990) and Sadagah and de Freitas (1990). The Monte Carlo methods requires a prerequisite information as to the intact length distribution which is assumed to be the negative exponential distribution in this paper.

Rock Mass Quality Range

The quantitative description of the rock mass by Deere (1964) gives rise to a single value of RQD. Later, the numerical simulation of the RQD using Monte Carlo method by Şen (1990) led to an ensemble of RQD values. Of course, the range is defined as the difference between maximum and minimum RQD values in a Monte Carlo experimental procedure which generates many synthetic scan lines each of which gives different RQD's. Unfortunately, the same rock mass has different properties in different directions (anisotropy) and locations (inhomogenity). Consequently one should expect that it has different RQD values along different directions. The range of the RQD is detected by a number of scan lines taken in the three dimensions of the rock mass. The numerical simulation of the joints spacings along each scan line using a computer program of Monte Carlo method developed for this purpose by Şen (1990) will produce a curve which represents the maximum and minimum values of RQD in a rock mass. Accordingly, three scan lines in the three dimensions will give different RQD ranges. The three curves then will give a reliable value of the range for the true RQD of that rock mass.

Three different rock masses of high, medium and low RQD were chosen in the Arabian Shield of Saudi Arabia for application. The studied rock types are granite, tonalite and schistosed tonalite which are of high, medium and low quality rock masses respectively. The high quality rock mass gives a narrow range of RQD values, (see Fig. 1) the maximum and minimum values of RQD are between 93 and 100

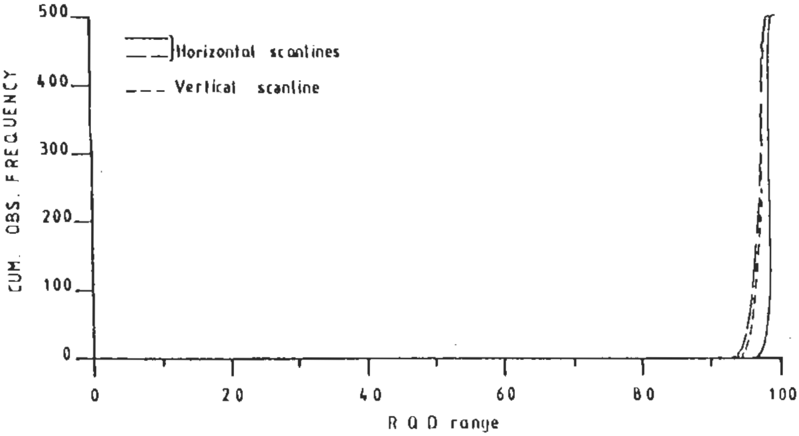

FIG. 1. RQD range of high quality rock mass against cumulative observed frequency.

which are rated as excellent by Deere (1964). The medium quality rock mass gives a wider RQD range (see Fig. 2). The maximum and minimum values of RQD are between 62 and 96 corresponding to fair to good quality. Finally, the low quality rock

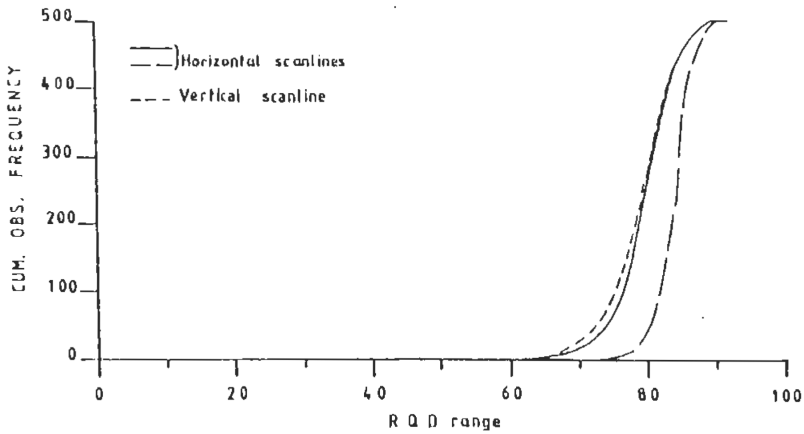

FIG. 2. RQD range of medium quality rock mass against cumulative observed frequency.

mass gives comparatively wider RQD range as shown in Fig. 3. It shows that the maximum and minimum values of RQD lie between 27 and 90, (rated poor to good). Comparison of the three figures for each rock mass quality shows that all RQD curves are generated neither from one minimum RQD value nor one maximum RQD value only. This indicates that the actual RQD value of the rock mass lies actu-

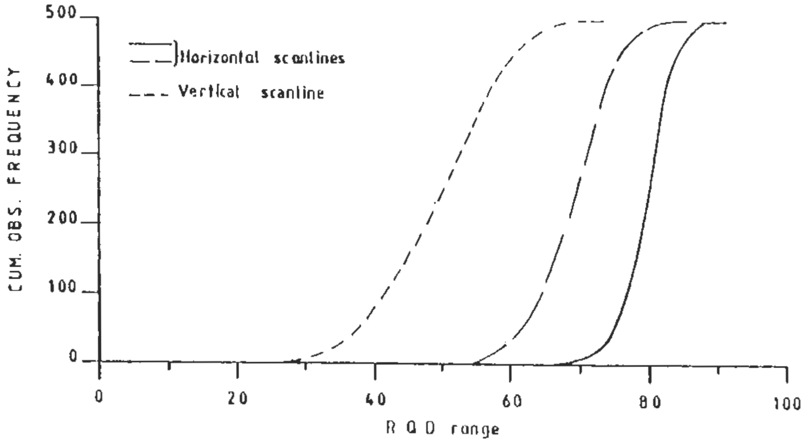

FIG. 3. RQD range of low quality rock mass against cumulative observed frequency.

ally within an area of RQD which is bounded by maximum and minimum RQD curves. In this area an infinite number of curves may occur, each curve representing a scan line taken along the rock mass in any of the three dimensions. Figures 1, 2 and 3 show that for each rock mass quality the vertical scan line generally gives the lowest RQD values of the rock mass. This is due to the structural setting, intensity and the spatial distribution of the joint sets allocated in the rock mass.

The Relationship Between RQD and the Threshold Value (TV)

The calculation of RQD value of the rock mass is based on the length of the intact rock mass not less than the threshold value, (TV) of 100mm as recommended by Deere (1964). This threshold value has no mathematical or physical background in calculating RQD. It is adopted as 100mm as a matter of convenience. Logically, different TV's lead to different RQD values. Accordingly, the numerical simulation computer program is modified to accept TV's ranging from 10 to 100mm. The RQD range was plotted against various TV's for high, medium and low quality rock mass in Figures 4, 5 and 6. These figures show that the relationship is negative curvilinear and inversely proportional. In general, the difference between the maximum and minimum values of RQD at threshold value of 100mm is high, whereas this difference decreases as TV decreases. The comparison between Figures 4, 5 and 6 at TV= 100mm show that as the rock mass quality decrease the difference between the maximum and minimum values of RQD increase. This indicates that the TV's of 100mm gives a very wide range of RQD of low quality rock mass which is completely undependable for design purposes in the fractured rock masses. Further comparison between these figures at TV= 40 to 100mm levels show that as the rock mass quality range decrease to a small range which may be considered as negligible error in measuring the RQD value.

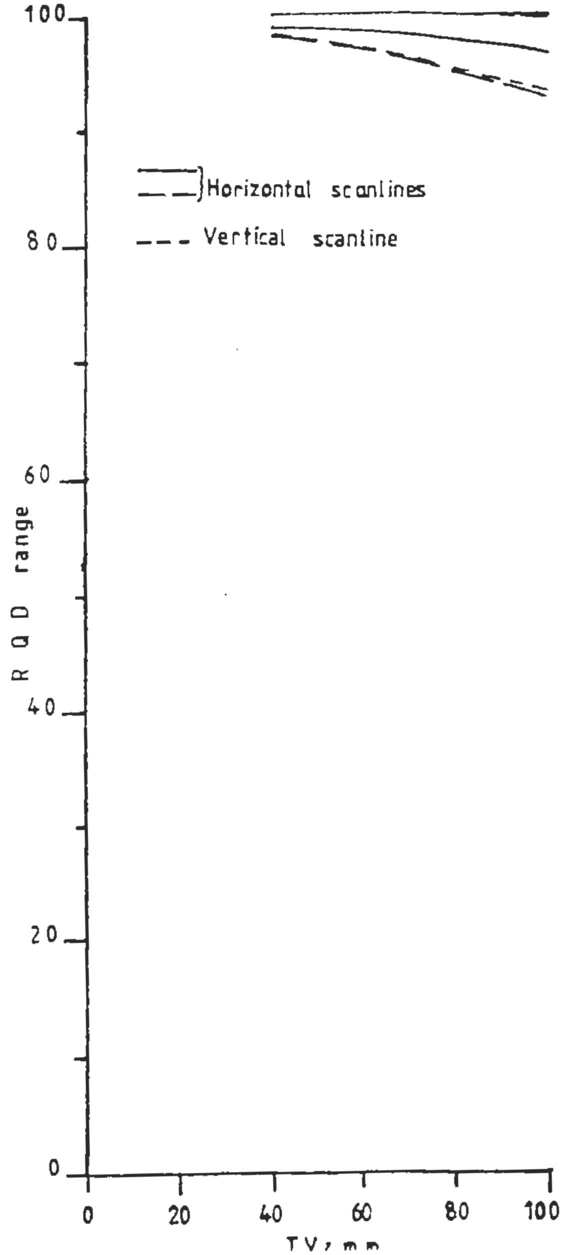

FIG. 4. The RQD range of high quality rock masses against different threshold values.

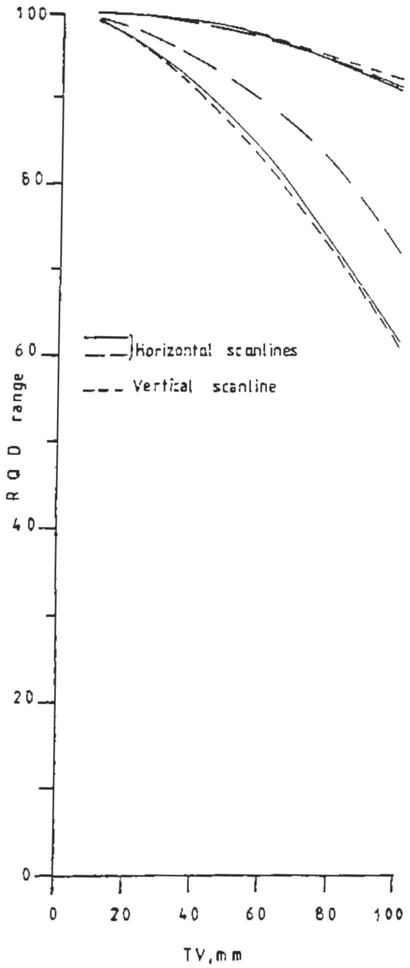

FIG. 5. The RQD range of medium quality rock masses against different threshold values.

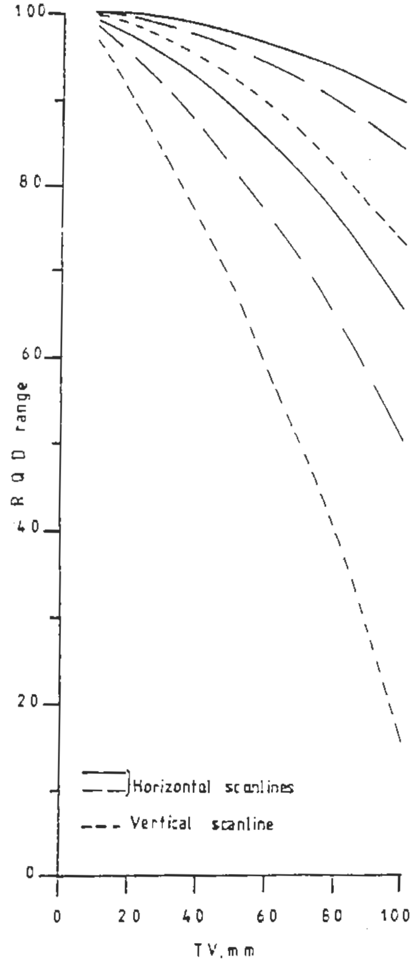

FIG. 6. The RQD range of low quality rock masses against different threshold values.

It could be driven from above discussions that the representative value will be dependable on RQD measured at a rather small TV values.

The Relationship Between RQP & RQR and the Cumulative Observed Frequency

The probability quantities of RQP and RQR was first introduced by Şen (1990) and used practically in the design of slopes cuts in rock masses by Sadagah (1989) and Sadagah *et al.* (1990) and in the evolution of the engineering geology maps by Sadagah and de Freitas (1990).

The RQP is defined quantitatively as the frequency distribution of the classical RQD, where the RQR is defined as the probability of RQD being less than a given design value.

A plot of RQP against the cumulative observed frequency shows a positive straight line relationship, the slope of which is 0.5 (see Fig. 7). It is rather surprising to notice

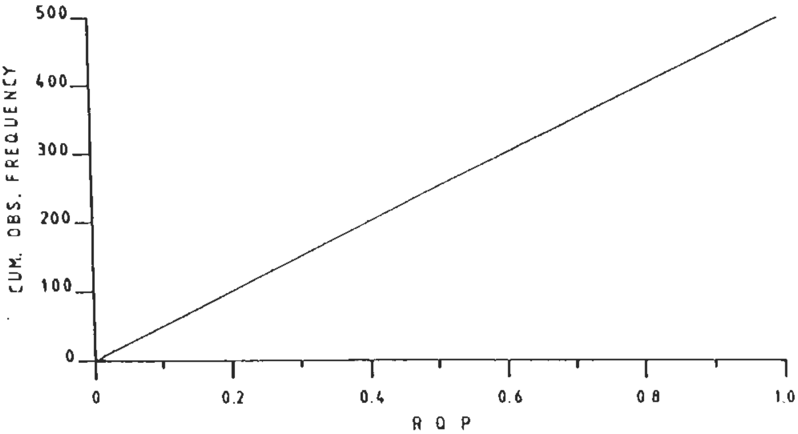

FIG. 7. The rock quality percent for all rock qualities against the cumulative observed frequency.

from this figure that the relationship is constant for all RQP measured at all TV levels. On the other hand, a plot of RQR against the cumulative observed frequency show a log-normal distribution relationship, (see Fig. 8), the apex of the curvature is at RQR of 0.21 and at cumulative observed frequency of 350.

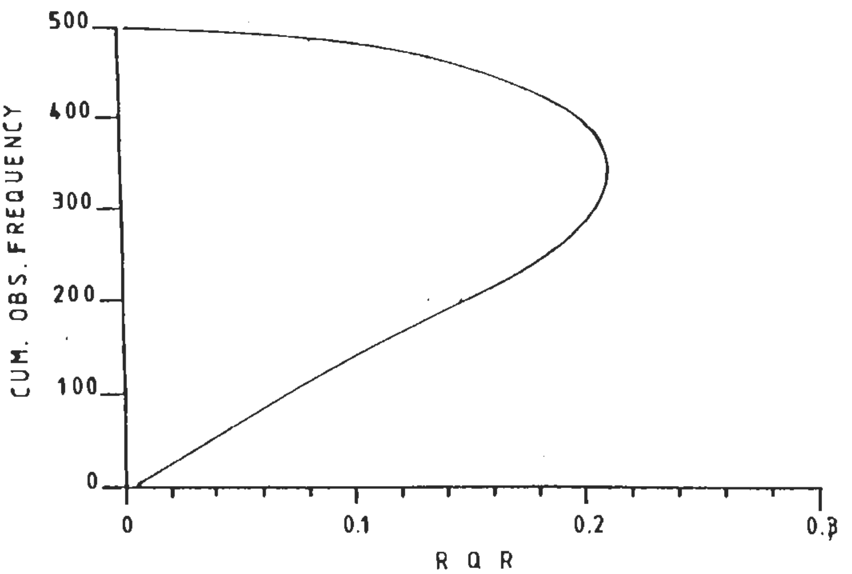

FIG. 8. The log-normal distribution relationship between RQR and the cumulative observed frequency.

RQD Range Percent

As indicated in Figures 4, 5 and 6, the range between the maximum and minimum values of low quality rock mass, also vary as TV values decrease. The difference between the minimum and maximum values of RQD will provide a new term called RQD range percent, calculated as follows :

$$\text{RQD range \%} = \frac{\text{maximum RQD} - \text{minimum RQD}}{\text{maximum RQD}} \times 100$$

The plot of RQD range difference percent against log TV and $\sqrt{TV}$ show a parabolic relationship, as in Figures 9 and 10.

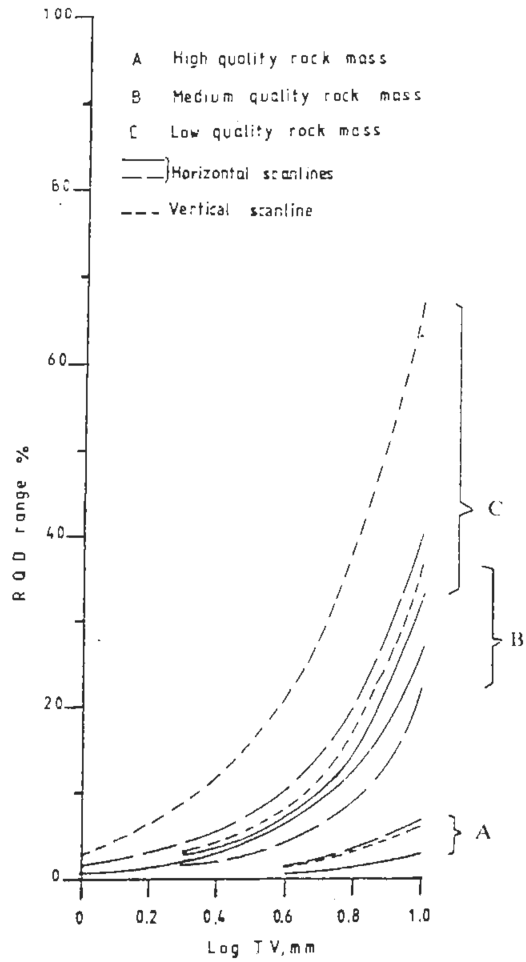

FIG. 9. The parabolic relationship between RQD range percent and log threshold value.

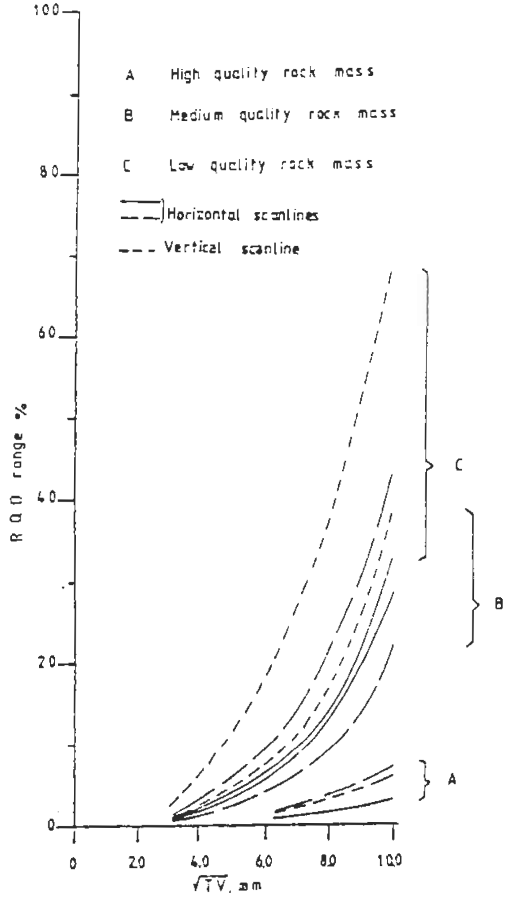

FIG. 10. The parabolic relationship between RQD range percent and square root of the threshold value.

Further plot of RQD range percent of high, medium and low rock mass quality against the corresponding TV values range from 10mm to 100mm on a log log scale show a positive trend straight line, (see Fig. 11). Each straight line represents one scan line measurement along one dimension of each rock mass quality. Table 1 shows that the variance of RQD range percent varies remarkably for different rock mass qualities at various TV's. It is possible to calculate from this Tables that for low rock qualities, the measured RQD at TV= 100mm, the error in measuring the RQD value varies from 26% to 70% which means that the low quality rock mass could be of better quality or worse quality than the measured RQD if only one scan line is used. Average error percent of measuring the RQD of different rock masses qualities is shown in Table 2.

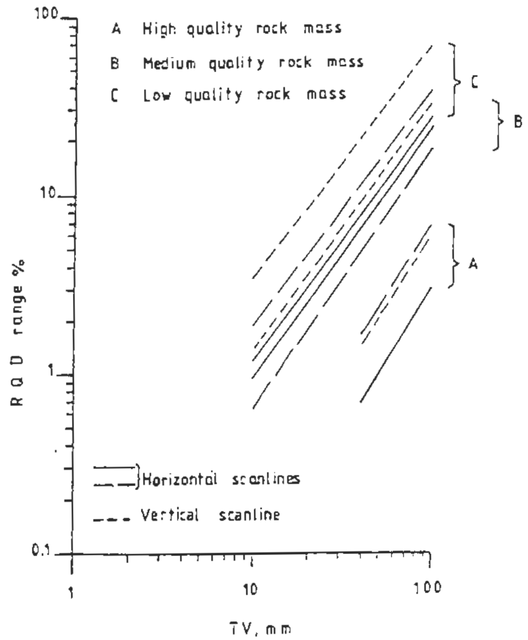

FIG. 11. Chart showing the measured RQD range at various threshold values.

TABLE 1. The RQD range percent for low, medium and high quality rock mass at various threshold values.

Rock mass quality	Threshold value		
	10 mm	40 mm	100 mm
High	negligible	0.7-1.4	3-6.8
Medium	0.6-1.4	4.8-9	18-33
Low	1.2-3.4	7.8-21	29-70

TABLE 2. The average errors of RQD range percent for high, medium and low quality rock mass at various threshold values.

Rock mass quality	Threshold value		
	10 mm	40 mm	100 mm
High	0.3	1.2	5.5
Medium	1.1	7.2	25
Low	2.1	13	46

The general relationship between the two variables can be found by a non-linear regression program leading to

$$\text{RQD range } \% = 0.049\ TV^{1.44}$$

The three measured scan lines of each rock mass quality are represented by one average line shown in Fig. 12, the equations of the average line representing the rock mass quality are as follows :

i) for low quality rock mass,

$$\text{RQD range } \% = 0.0037\ TV^{1.322}$$

ii) for medium quality rock mass,

$$\text{RQD range } \% = 0.04\ TV^{1.406}$$

iii) and finally, for high quality rock mass,

$$\text{RQD range } \% = 0.0037\ TV^{1.593}$$

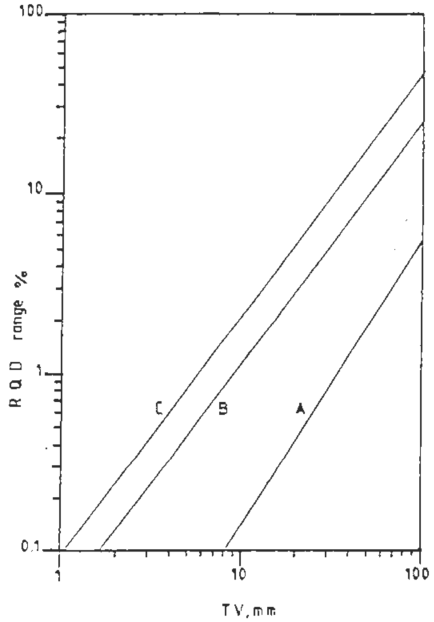

FIG. 12. Chart showing the average expected error of the RQD at various threshold values.

In Fig. 12 the area below line A is valid for every high quality rock mass, and the area between lines A and B represent the medium to high quality rock mass, while the area between lines B and C represents low to medium quality rock mass, accordingly the area above line C represents low and very low quality rock mass.

The chart shown in Fig. 12 show that if the threshold value of 100mm is used to derive the RQD of any rock type, the average error percent in measuring the RQD range difference is increasing however if the threshold value decreases to 10mm the average range error percent decreases.

Conclusion

The following conclusions can be drawn from this study.

1. Figures 1 to 6 show that the RQD has maximum and minimum values forming

a range of RQD values of the rock mass.

2. The values of the RQD depend on the threshold value used to calculate it. If TV = 100mm is used, as recommended by Deere (1964), in calculating the RQD then an error is expected to take place. The amount of this error increases as the rock mass quality decrease. However, as the TV decreases below 40mm the error in calculating RQD decrease to a negligible values. This reveals that there is no recommendable definite threshold value in calculating the exact RQD. However, the more representative RQD value will be obtained as the threshold value becomes small which could be depicted by the numerical analysis utilizing the Monte Carlo method.

3. It is shown in Fig. 12 that if the threshold value of 100mm is used to determine the RQD of the rock mass the average error percent of measuring the RQD value of any rock mass is high. However, the average error percent decreases sharply if the threshold value of 10mm is used. This indicates that the commonly used threshold value of 100mm is not accurate to determine the actual RQD of the rock mass. Therefore, it is recommended to use the minimum, as possible threshold value in determining the actual rock mass designation.

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مجـــال مَـعْـــلَم جـــودة صخـــور وقيمـــة المرجـــع

بهاءالدين هاشم صدقــة

كلية علوم الأرض ، جامعة الملك عبد العزيز ، جـــدة ، المملكة العربية السعودية

المستخلص . مَعْلَم جودة الصخور (م ج ص) هي أسهل طريقة حساب لتعيين جودة الكتل الصخرية لأغراض التصميم . تستعمل قيمة المرجع ١٠٠ مليمتر حتى الآن لحساب م ج ص ، بدون أي أساس علمي أو فيزيائي لاختيار هذه القيمة . إذا كان حساب م ج ص يعتمـد على هذه القيمة فإنه سيعطينا تقييم غامض لقيمة م ج ص الحقيقية للكتلة الصخرية المعنية ، وبالتالي قيم مرجع مختلفة يمكن أن تؤدي إلى م ج ص متعددة . في هذه الورقة اختيرت قيم متعددة لقيمة المرجع من ١٠ مليمتر إلى ١٠٠ مليمتر لحساب تأثيرها على م ج ص وذلك باستعمال برنامج حسوب آلي باستخدام طريقة مونت كارلو . المعيار المستعمل في تقييم قيمة المرجع هو تغيرها مع مجال م ج ص والمعرف بأنه الفرق بين أكبر وأقل قيمة لـ م ج ص والتي تحدث خلال محاكاة م ج ص بوساطة تقنية مونت كارلو . النتائج تظهـر علاقـة عكسية الفـرق بين مجالات م ج ص وقيمة المرجع . هذا البحث يوصي باستعمال قيمة مرجع مابين ١٠ مليمتر إلى ٤٠ مليمتر لحساب م ج ص الحقيقية للكتلة الصخرية ، وذلك حتى تحصل على أقل خطأ متوقع .