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The Rock Quality Designation (RQD) Index in Practice

REFERENCE: Deere, D. U. and Deere, D. W., **"The Rock Quality Designation (RQD) Index in Practice,"** *Rock Classification Systems for Engineering Purposes, ASTM STP 984*, Louis Kirkaldie, Ed., American Society for Testing and Materials, Philadelphia, 1988, pp. 91–101.

ABSTRACT: The Rock Quality Designation (RQD) index was introduced 20 years ago at a time when rock quality information was usually available only from geologists' descriptions and the percent of core recovery. The RQD is a modified core recovery percentage in which unrecovered core, fragments and small pieces of rock, and altered rock are not counted so as to downgrade the quality designation of rock containing these features. Although originally developed for predicting tunneling conditions and support requirements, its application was extended to correlation with *in situ* rock mechanical properties and, in the 1970s, to forming a basic element of several classification systems. Its greatest value, however, remains as an exploratory tool where it serves as a red flag to identify low-RQD zones which deserve greater scrutiny and which may require additional borings or other exploratory work. Case history experience shows that the RQD red flag and subsequent investigations often have resulted in the deepening of foundation levels and the reorientation or complete relocation of proposed engineering structures, including dam foundations, tunnel portals, underground caverns, and power facilities.

KEY WORDS: rock mechanics, Rock Quality Designation index, modulus of deformation, jointed rock, tunnel supports, rock mass classification, core logging

The Rock Quality Designation (RQD) index has been used for over 20 years as an index of rock quality. It measures the percentage of "good" rock within a borehole. It was developed by the senior author originally as a means of qualitatively describing whether a rock mass provided favorable tunneling conditions. It is now used as a standard parameter in drill core logging and forms a basic element of several rock mass classification systems [*1*,*2*]. Perhaps its greatest value is its simplicity, which allows for the delineation of zones of poor quality rock that could adversely affect engineering structures.

This paper presents the background for the development of the RQD, the recommended procedure for measuring RQD, and examples of its use in practice.

Background

In 1963 a paper was published by Deere [*3*] entitled "Technical Description of Rock Cores for Engineering Purposes" in the first volume of *Felsmechanik und Ingenieurgeologie* (Rock Mechanics and Engineering Geology). This would have been an excellent international forum for introducing the RQD concept but it was not included because it had not as yet been devised. It was in the following year that the senior author developed the RQD concept to assist in the siting and the

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design of tunnels and large caverns in granite at the Nevada Test Site. In 1965 it was extended to the design of highway tunnels in massive quartzite, gneiss, and schist in North Carolina.

Because of its success in these early applications to tunnels as actually designed and built, the RQD concept appeared worthy of a continuing research effort. It was at the University of Illinois that the RQD concept was first applied to a wider range of rock engineering problems.

In 1967 Deere and his colleagues at the University of Illinois [*4*] presented for the first time in published form the RQD concept of rock quality logging together with some correlations with velocity indices, fracture frequency, and *in situ* modulus values.[3] The method of measuring RQD was given as well as a brief discussion of some of the difficulties involved in determining it.

The published work that introduced RQD to an international audience, and that no doubt was responsible for its rapid growth in use in many countries, was *Rock Mechanics in Engineering Practice* (1968) [*5*]. This contained chapters by Deere [*6*] and by Hendron [*7*] in which the RQD concept and applications were discussed.

Research continued at the University of Illinois on tunneling and the application of the RQD index under the sponsorship of the U.S. Air Force and the U.S. Department of Transportation. This research lead to several publications in the late 1960s and early 1970s [*8-12*]. During the 1970s the RQD index began to be used as a basic parameter in several classification systems for rock masses (Bieniawski [*1,13,14*], Barton et al [*2*]).

Recommended Procedure for RQD Logging

In this section several of the procedures for the RQD logging of cores are reviewed. The procedures as given in the original references [*4,6*] are discussed together with some of the problems encountered and modifications proposed by others or by the authors.

The RQD is a modified core recovery percentage in which all the pieces of *sound* core over 100 mm (4 in.) long are summed and divided by the length of the *core run*. The correct procedure for measuring RQD is illustrated in Fig. 1. The RQD index is an index of rock quality in that problematic rock that is highly weathered, soft, fractured, sheared, and jointed is counted against the rock mass. Thus it is simply a measurement of the percentage of "good" rock recovered from an interval of a borehole.

Core Size

The RQD was originally developed for NX-size core (54.7 mm [2.16 in.] diameter). Deere [*6*] specified that a minimum NX-size core obtained with double-tube core barrels should be used. The authors' experience has shown that other core sizes and drilling techniques are also applicable to recording RQD measurements. Core sizes between BQ and PQ with core diameters of 36.5 mm (1.44 in.) and 85 mm (3.35 in.), respectively, are applicable for measuring RQD so long as proper drilling techniques are utilized that do not cause excess core breakage and/or poor recovery. The NX-size and NQ-size (47.5 mm [1.87 in.]) remain the optimal core size for measuring RQD and are the most common sizes used in rock exploration for geotechnical investigations.

Variable length requirements for RQD measurements have been proposed [*15*]. For example, instead of using the standard 100 mm (4 in.) requisite length, a length equal to double the core diameter was advocated (such as a 60 mm length when using 30 mm diameter AX core). The authors believe that a 100 mm (4 in.) requisite length should be used in all cases for the purposes of standardization and comparison. Moreover, with good drilling techniques the lengths of the

[3] An incorrect reference inadvertently cited in this paper credited Deere with the introduction of RQD in his 1963 paper [*3*].

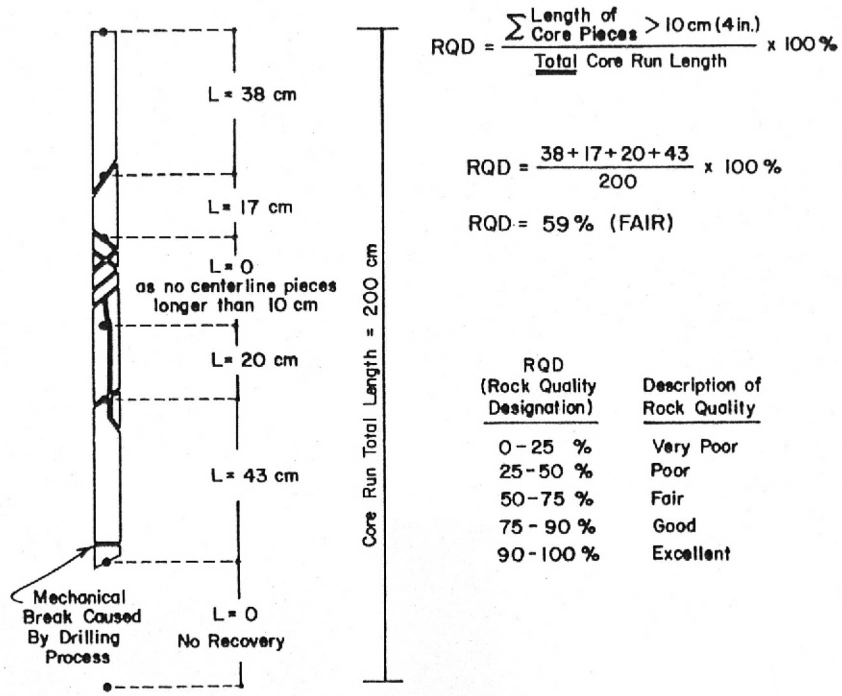

FIG. 1—*Procedure for measurement and calculation of RQD.*

core pieces will be the same regardless of core diameter, since the spacing of natural unbonded joints does not change.

Measurement of Core Lengths

There are various ways to measure the length of a core piece. The same piece of core could be measured along the centerline, from tip to tip, or along the fully circular barrel section. The recommended procedure is to measure the core length along the centerline (Fig. 1). This method is advocated by the International Society for Rock Mechanics (ISRM) Commission on Standardization of Laboratory and Field Tests [*16*]. The reason that the centerline measurement is preferred is to avoid unduly penalizing the quality of the rock mass for cases where fractures parallel the borehole and are cut by a second set.

Core breaks caused by the drilling process should be fitted together and counted as one piece. Drilling breaks are usually evidenced by rough fresh surfaces. For schistose and laminated rocks, it is often difficult to discern natural breaks from drilling breaks. When in doubt about a break, it should be considered as natural, in order to be conservative in the calculation of RQD.

Some rocks, such as shales and claystones, often break up into small disks or chips with time. Rock core with initial RQD of 100% may break up into core with zero RQD. This is owing to one or more deleterious processes of slaking, desiccation, stress relief cracking, or swelling. Thus it is imperative that RQD be logged on site when the core is retrieved. The breakup of the core over time, however, should be noted on the drilling log, since this is evidence of a rock property that may control design of a structure.

Assessment of Soundness

Pieces of core that are not "hard and sound" [*6*] should not be counted for the RQD even though they possess the requisite 100 mm (4 in.) length. The purpose of the soundness requirement is to downgrade the rock quality where the rock has been altered and weakened either by agents of surface weathering or by hydrothermal activity. Obviously, in many instances, a decision must be made as to whether or not the degree of chemical alteration is sufficient to reject the core piece.

One procedure, which the authors have used, is not to count a piece of core if there is any doubt about its meeting the soundness requirement (because of discolored or bleached grains, heavy staining, pitting, or weak grain boundaries). This procedure may unduly penalize the rock quality, but it errs on the side of conservatism. A second procedure that occasionally has been used by the authors in recent years is to include the altered rock within the RQD summed percentage but to indicate by means of an asterisk that the soundness requirement has not been met. The advantage of the method is that RQD* will provide some indication of the rock quality with respect to the degree of fracturing while also noting its lack of soundness.

Bieniawski [*13*] in his 1974 paper addressed the soundness requirement as follows:

> . . . Since only hard, sound core is included in RQD determination, this means that rock core which is highly weathered receives zero RQD. For this purpose "highly weathered rock" means that weathering extends throughout the rock mass. The rock material is partly friable, has no lustre and all material except quartz is discolored or stained. Highly weathered rock can be excavated with a geologist's pick. . .

The assessment of the soundness requirement merits further consideration. There is no disagreement with Bieniawski's suggestion that "highly weathered rock" receives zero RQD. Using the weathering grades of the International Society for Rock Mechanics [*16*] (I-Fresh; II-Slightly Weathered; III-Moderately Weathered; IV-Highly Weathered; V-Completely Weathered; VI-Residual Soil), there is no doubt about Grade I-Fresh being included and Grade VI-Residual Soil being excluded from the RQD count. The remaining four categories all represent degrees of weathering where judgement decisions must be made.

Grade II-Slightly Weathered is described [*16*] as follows: "Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discolored by weathering and may be somewhat weaker externally than in its fresh condition." Since the alteration is limited to discoloration, possibly with somewhat lowering of strength, it appears logical to accept this degree of "slightly weathered" Grade II in the RQD count. The Grade V-Completely Weathered state by its very name eliminates any core so described from the RQD count. Its description is [*16*]: "All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact."

The two remaining categories are III-Moderately Weathered and IV-Highly Weathered. The latter category is the one which Bieniawski [*13*] eliminated from the RQD count. The ISRM description is [*16*]: "More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones." Little [*17*] in his description of residual tropical soils uses the same terminology, Highly Weathered, and states: "Rock so weakened by weathering that fairly large pieces can be crumbled in the hands. Sometimes recovered as core by careful rotary drilling. Stained by limonite." It is clear that Highly Weathered rock should not be included in the RQD count, since it has been weathered to the point that it can be crumbled in the hands.

The Grade III-Moderately Weathered category is described [*16*] as follows: "Less than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a continuous framework or as corestones." Little [*17*] states for Moderately Weathered

rock: "Considerably weathered. Possessing some strength; large pieces (e.g. NX drill cores) cannot be broken by hand. Often limonite stained. Difficult to excavate without use of explosives." Because this category is close to the borderline, it is of interest to consider another description [*18*]; "Term-Moderately Weathered, Grade III, Abbreviation Mw . . . The rock is discolored; discontinuities may be open and surfaces will have greater discoloration with the alteration penetrating inwards; the intact rock is noticeably weaker, as determined in the field, than the fresh rock."

It is recommended that Grade III-Moderately Weathered rock be accepted in the RQD count but that it also be identified with an asterisk as being less than sound. However, it possesses sufficient strength, although moderately weathered, to resist hand breakage of core pieces.

In summary, Grades I (Fresh) and II (Slightly Weathered) are included in the RQD count, as is Grade III (Moderately Weathered) but with the asterisk qualifier. Grades IV (Highly Weathered), V (Completely Weathered), and VI (Residual Soil) are disregarded in the RQD count.

Length of Coring Run

The RQD index is sensitive to the length of the core run. For example, a 300-mm (11.8-in.)-long, highly fractured zone within a massive rock would result in RQD values of 90%, 80%, and 40%, for respective run lengths of 3 m (12.9 ft), 1.5 m (4.9 ft), and 0.5 m (1.6 ft). Thus, the shorter the run length, the greater the sensitivity of the RQD and the lower its value (becoming equal to zero for a 300 mm [11.8 in.] run encompassing the fractured zone).

The authors recommend that in general the calculation of the RQD be based on the actual drilling-run length used in the field, preferably no greater than 1.5 m (5 ft). Actual length and nature of zones of poor rock should be described in the drilling log and could be supplemented by calculation of RQD on variable "artificial run lengths" in order to highlight poor quality zones. Many times this discrimination occurs naturally in the drilling process; as zones of poor rock are encountered, the run lengths are shortened to prevent blockage of the coring bit and to enhance core recovery. The ISRM Commission on Standardization of Laboratory and Field Tests [*16*] recommends RQD logging using variable "run lengths" to separate individual beds, structural domains, weakness zones, etc., so as to indicate any inherent variability and provide a more accurate picture of the location and width of zones with low RQD values.

RQD Use in Engineering Practice

Early Site Evaluation

Generally, some of the first data from a site study are the core recovery data and the RQD values recorded on the logs of the exploratory borings. The percent of core recovery, the RQD measurements, and the geologic descriptions of the cores are determined at the drilling site by the field engineering geologist within minutes of recovering the cores. This procedure is nearly standard practice for major projects in most countries.

The boring logs, with the above-described information clearly presented, in conjunction with geologic mapping provide early project information on distribution of rock types, degree and depth of rock weathering, and zones of rock weakness and close fracturing. The project design team, which includes the engineering geologist and rock mechanics specialist, may use this information for early estimates of the required depths of excavation for founding the structures and of any potential problems of bearing capacity, settlement, or sliding or of obtaining adequate rock from quarries for concrete aggregate, rockfill, or large rock pieces for riprap.

It is at this stage that RQD has been a particularly helpful tool in comparing one boring with another, one depth with another, and one part of a site with another. A study of the results may lead to relocation of structures such as dams, shafts, and underground powerhouses into areas of better rock conditions. Or, it may lead to additional exploration for checking on suspected weak zones—either by more borings, by geophysical methods, or by trenches and exploratory shafts.

Appropriate design decisions at this early planning and preliminary design phase in locating the structures in the best rock area away from zones of deep weathering, shearings, or faulting may result in savings of millions of dollars in construction costs and project delays. The RQD values, as determined with depth and across the site, have been found by experience to be extremely helpful in making these design decisions. The authors consider this application of RQD to be its greatest use in engineering practice.

Red-Flag Effect of Low RQD

Whether in the early site investigation phases or in a later design phase, a low RQD value should be considered a "red flag" for further action. The reason for the low RQD value must be determined: poor drilling techniques, core breakage upon handling, stress-relief or air-slaking, thinly bedded or closely jointed zone, or zone of poor rock conditions with shearing, weathering, etc. It is the last condition that would be of most concern. If this condition were found to exist, additional borings or other types of exploration might be required to assess the orientation and characteristics of the weak zone and its potential effect on the engineering structure to be built.

One method of highlighting the "red-flag" zones that has been used by the authors is as follows. Both the total percentage of core recovery and of the RQD are plotted as a function of depth on the same graphical column of the boring log; this plot is easy to draft as the RQD value is always equal to or less than the core recovery. To highlight RQD values less than 50%, the areas that are included between the line representing the low RQD value and the 50% line are colored red (on the prints).

A zone of RQD of 45% would have only a narrow colored band (5%), while a zone of very poor rock represented by, say, 12% would have a wide colored band (38%). Thus the zone would be adequately "red flagged"; the worse the rock, the larger the red flag. By use of this simple technique a quick comparison can be made among boring logs in various parts of the site and, upon occasion, a weak structural feature can be followed from boring to boring.

The depth of weathering and its general decrease in severity with depth as indicated by the RQD may be depicted quite well with the red-flag concept. The depth of required foundation excavation often can be determined in a preliminary way with a quick study of the red-flag display.

RQD Index in Tunneling

As noted previously, the RQD concept was developed for tunneling, firstly as an aid in siting tunnels and shafts in the best ground conditions possible, and secondly as a guide in assessing tunneling conditions and selecting the initial supports. References *8* to *11*, published in the 1969–1970 period, presented tables relating tunnel support and RQD based on the University of Illinois sponsored research efforts. Cecil [*19*] published in 1970 his work on correlation of RQD with rock bolt-shotcrete support as used in Scandinavia.

Merritt [*12*] in 1972 made use of his recent experience and the works cited above to present an improved version based on 58 cases which included tunnel widths ranging from 2 m (6 ft) to 20 m (60 ft). He compared the support criteria as shown by his system as a function of tunnel width and RQD with those proposed by Peck et al [*10*] and Cecil [*19*]. Table 1 is based on Merritt's Fig. 3 [*12*] and has been selected for a 6-m (20-ft)-wide tunnel, a common tunnel size for pressure tunnels and a single-track rapid transit tunnel.

Merritt [*12*] points out problems associated with any attempt to precisely correlate rock quality with the tunnel support actually used:

TABLE 1—*Comparison of RQD and support requirements for 6-m (20-ft)-wide tunnel (data interpolated from Merritt* [12]).

	No Support or Local Bolts	Pattern Bolts	Steel Ribs
Peck et al, 1969 [*10*]	RQD 75–100	RQD 50–75 (1.5–1.8 m spacing) RQD 25–50 (0.9–1.5 m spacing)	RQD 50–75 (light ribs on 1.5–1.8 m spacing as alternative to bolts) RQD 25–50 (light-to-medium ribs on 0.9–1.5 m spacing as alternative to bolts) RQD 0–25 (medium-to-heavy circular ribs on 0.6–0.9 m spacing)
Cecil, 1970 [*19*]	RQD 82–100	RQD 52–82 (alternatively 40–60 mm shotcrete)	RQD 0–52 (ribs or reinforced shotcrete)
Merritt, 1972 [*12*]	RQD 72–100	RQD 23–72 (1.2–1.8 m spacing)	RQD 0–23

> . . . Unfortunately, the selection of tunnel support does not always depend upon the actual rock conditions. The method preferred by the contractor may be based on a favorable unit price for steel sets as opposed to bolts, or the lack of adequate equipment for the rapid placement of either sets or bolts. The preference for sets in the first place may be based on an overcautious safety program . . . although no method for predicting tunnel support criteria is foolproof, the writer believes this system can be of great value for design and estimating support purposes. The RQD method of core analysis is simple, inexpensive, and reproducible and it has an advantage over joint frequency, for example, in that joints can only be counted in recovered core . . . The RQD support criteria system has limitations in areas where the joints contain thin clay fillings . . .

Use of RQD in Later Rock Classification Systems

Bieniawski [*1*] in 1973 and Barton et al [2] in 1974 made use of RQD and its correlations in the development of new classification systems. The new systems variously include effects of joint characteristics, compressive strength, *in situ* stress, water conditions, orientation of fractures, and others which are not specifically included in the RQD analysis. The inclusion of these additional parameters decreases the simplicity of the RQD analysis but increases the classification systems' discriminatory and correlative capabilities.

Additional comments concerning the new systems are not included herein, since companion papers by the founders of those systems are included in this volume. However, it should be noted that one or the other of these systems (and, occasionally, both) are increasingly being used in the design and construction monitoring of international projects worldwide.

Prediction of In Situ *Modulus*

A secondary outcome of the RQD research in the late 1960s at the University of Illinois was the correlation of the RQD (or velocity ratio) with the *in situ* modulus of deformation. Obviously, the greater the fracturing and alteration, the lower the RQD and the lower the modulus; correlations showed this to be true [*4,7,8,20*].

The senior author over the last decade has not used the RQD correlation extensively but has employed for preliminary estimates the unpublished correlation of seismic *P*-wave velocity and the *in situ* modulus, or the correlation with the shear wave frequency of Schneider as given by Bieniawski [*21*]. Bieniawski's correlation of the Geomechanics Rock Mass Rating (RMR) and the *in situ* modulus of deformation [*21*, Fig. 8] also gives an additional correlative tool. For critical cases, the authors prefer large-scale *in situ* testing where the loading direction in the test approximates that in the prototype structure so that the significant rock joints can be appropriately tested.

Case Histories Illustrating RQD Usage

Case History No. 1—Washington, D.C., Metro: General Rock Quality

A major use of RQD on the projects of the Washington Metropolitan Area Transit Authority (WMATA), extending over the past two decades and continuing today, is as an indicator of suitable rock conditions for siting the various structures as to location and depth below the surface (including single-track, double-track, and crossover tunnels; mined stations and equipment vaults; ventilation and access shafts; and open and braced cuts). The RQD is presented on the boring logs along with the core recovery and is also used in preparing geological sections for the report on subsurface investigations prepared by WMATA's General Soils Consultant (GSC). The planners and engineers of WMATA and of their General Engineering Consultant (GEC) use the rock quality data as an important input for selecting or modifying the tunnel grade, for selecting positions of stations and shafts, and for preparing preliminary cost estimates.

The detailed design of the various segments of the subway are done by a number of individual design firms, working under the general guidelines of the GEC. One of the duties of the Section Designer selected for a particular segment is to prepare a report entitled "Geotechnical Basis for Design and for Construction Specifications" for his segment. This document is based on the information in the reports of the General Soils Consultant and interprets the information for design and construction, including the data on RQD and rock quality. Both this interpretative geotechnical design and construction report prepared by the Section Designer and the subsurface investigation reports by the GSC become part of the contractual documents.

The GSC over the last two decades periodically has made minor changes and adaptations in his boring log format, geological sections, and legend nomenclature as new information has become available. Present terminology is illustrated by a 1986 report by the GSC, "Supplementary Subsurface Investigation" [*22*]. Excerpts from that report regarding terminology for weathered rock and RQD values are given herein:

- *DEC (Decomposed Rock)*—Generally soil-like, can be crumbled by slight hand pressure, but the rock texture and structure are often preserved.
- *HiW (Highly Weathered Rock)*—Generally rock-like, can be broken easily, but crumbles with difficulty by hand.
- *MdW (Moderately Weathered Rock)*—Fabric stained rusty brown, can be indented by steel nail, breaks only with difficulty.
- *SlW (Slightly Weathered Rock)*—Open discontinuities are weathered, and coated, but only slight weathering of rock mass, generally not indented by steel nail.
- *UnW Ex Jts*—Weathering limited to the surface of discontinuities, fabric fresh throughout, but most joints show rusty stain and/or soil filling material.
- *UnW Inc Jts*—Rock mass and discontinuities are unweathered, only occasional joints show rusty stain, practically no soil filling.

The same drawing (F-G-288) of Ref *22* which has the above definitions also contains a note explaining the procedure used in delineating the "transitional zone" between the residual soil and rock-like "weathered rock," an important and difficult zone for design and construction and one that has led to many construction problems on WMATA projects. Both core recovery and RQD are used:

> . . . The natural materials overlying bedrock are derived from weathering and decomposition of the parent rock in-situ. On the geological sections the natural overburden materials above bedrock are divided into two categories:
>
> Zone (D): Decomposed rock (residual soil)
>
> Zone (D) to (WR): Transition, decomposed rock to weathered rock.
>
> The upper residual zone is composed almost entirely of soil-like material. The lower "transition" zone is expected to contain both soil and rock-like materials in roughly equal proportions. The division between these two zones is generally taken in the borings at a standard sampler penetration resistance value of approximately 100 blows per foot. The "Approximate Top of Weathered Bedrock" constitutes the boundary between the transition zone and bedrock which exhibits essentially rock-like characteristics. This boundary generally is taken where rock core recoveries exceed approximately 50 percent and/or RQD values exceed approximately 10 percent. . . .

The boundaries of the residual soil, transition, and weathered bedrock are shown on the geological sections, as are zones of jointing within the rock mass in accordance with the following:

- WR – Weathered and Jointed Bedrock, RQD 10–50%.
- J – Jointed Bedrock (may have weathering along joints but little to no alteration of mineral fabric):
  - HJ, Highly Jointed, RQD less than 50%.
  - MJ, Moderately Jointed, RQD 50–75%.
- R – Relatively Sound to Sound, RQD greater than 75%.

In core logging the GSC engineers and geologists include all rock core, even if moderately to highly weathered, provided they meet the 100-mm (4-in.)-length criterion. Daugherty [*23*] presents a good description of Washington Metro's geology and its use together with RQD in the siting and design evaluations.

Case History No. 2—Washington, D.C., Metro: Shear Zone Problems

The effect of shear zones on the design and construction of the WMATA underground construction in rock has amply been illustrated by the occurrence of displacements of the arch and walls, of fallouts, of the necessity for placing additional supports, and of controversial delays and associated costs. Many of these problems and their association with shear zones (mostly parallel to the foliation) have been described in the tunneling literature [*23-27*].

Reference *22*, reporting on the subsoil investigations for the double crossover, Section B010c, Glenmont Route, notes that the purpose of the additional borings ". . . was to delineate in greater detail the bottom of the weathered rock and the shear zones in the crossover area." It was noted in the summary and conclusions that three shear zones were delineated that will cross the future excavations and that will require special care in design and construction. The shear zones were associated with zones of ". . . poor recovery and low RQD."

Reference *25* describes the geology of several of the Metro projects and notes that the rock quality, as defined by the RQD of the cores, ranges from fair to good ". . . except in the shear zones where rock quality is poor to very poor." It notes the type of loosening and fallout of blocks bounded by foliation shear zones for tunnels crossing the zones at different angles. An example is given where four supplemental core borings were drilled from the basement of an adjacent building into the future tunnel area. The core was logged for rock quality (RQD) and provisionally oriented by means of the foliation orientation (which was known from adjacent areas). Four major foliation shear zones were mapped from the borings, of which three could be correlated with exposures in a shaft and tunnel nearly 100 m (328 ft) distant. When the new tunnels were excavated, the shear zones were encountered within 0.3 m (1 ft) of the anticipated positions.

Cording and Mahar [26] in 1974 presented the most detailed account of the effect of jointing and shear zones on tunneling problems on the Metro using nine case histories. On the basis of their analyses of the problems they listed six determinations that should be made during the exploration for tunnels driven through foliated metamorphic rock. A portion of the third item will be excerpted as it makes a fitting closing statement for this paper on the use of the RQD in practice:

> . . . 3. *Determine location of major low quality zones along alignment.* Low quality zones in the core boring can be determined by logging the degree of weathering and the RQD in the core. Such information should be interpreted to determine if the low quality zones are due to weathering, foliation shear zones or other shear zones, major transverse fault zones or fracture zones, pegmatites, slabbing of the rock along previously intact foliation planes, or breakage during drilling . . . Evidence of slickensides, filling and fractured rock permitted designation of many of the low quality zones as foliation shear zones . . . typically have RQD values less than 50% in the core . . .

The use of RQD cannot be separated from keen geological observation and from a knowledge of the effect of weaknesses, such as foliation shear zones, on design and construction.

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STP 984

Rock Classification Systems for Engineering Purposes

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ASTM
1916 Race Street
Philadelphia, PA 19103

(1988)

LIBRARY OF CONGRESS
Library of Congress Cataloging-in-Publication Data

Rock classification systems for engineering purposes / Louis Kirkaldie, editor.
(Special technical publication; (STP) 984)
Papers from the Symposium on Rock Classification Systems for Engineering Purposes, held in Cincinnati, Ohio, June 25, 1987, and sponsored by ASTM Committee D-18 on Soil and Rock.
Includes bibliographies and index.
"ASTM publication code number (PCN) 04-984000-38."
ISBN 0-8031-0988-1
1. Engineering geology—Congresses. 2. Rocks—Classification—Congresses. I. Kirkaldie, Louis. II. Symposium on Rock Classification Systems for Engineering Purposes (1987: Cincinnati, Ohio) III. ASTM Committee D-18 on Soil and Rock. IV. Series: ASTM special technical publication; 984.
TA703.5.R63 1988
624.1′51—dc19 88-5091
CIP

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Each paper published in this volume was evaluated by three peer reviewers. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of these peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM.

Printed in Ann Arbor, Mich.
June 1988

Foreword

The Symposium on Rock Classification Systems for Engineering Purposes was held in Cincinnati, Ohio, on 25 June 1987. ASTM Committee D-18 on Soil and Rock served as sponsor of the event. The symposium chairman was Louis Kirkaldie, USDA Soil Conservation Service, who has also edited this publication.