

Evaluation of RMR for Meta-Sedimentary Rocks in Hong Kong: Challenges and Potential Solutions

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ABSTRACT

Meta-sedimentary rocks are distributed over several areas of Hong Kong, including Sai Kung and Shatin, but are especially prevalent in the Northern New Territories. With the proposed development of the Northern Metropolis in the Northern New Territories in its preliminary stages, there is an increased awareness of the complexity of these meta-sedimentary rocks and how their rock mass and material properties may affect foundation design.

The Rock Mass Rating (RMR) system, developed by Bieniawski, has been adopted in GEO Publication No. 1/2006 for estimating allowable bearing pressure and deformation modulus for foundation design in Hong Kong. Over the years, the RMR system has been proven useful for piling works and applicable to various rock types, including meta-sedimentary rocks. Meanwhile, as the use of the RMR system in meta-sedimentary rocks is becoming prevalent in Hong Kong for estimating the allowable bearing pressures, some practitioners encountered challenges when evaluating RMR for these rocks. These difficulties arise primarily from the inconsistencies in the assessment of the rating of RMR parameters by different practitioners, taking cognisance of the limitations of rock joint descriptions in conventional borehole logging practices.

This paper examines the challenges encountered in RMR assessments for meta-sedimentary rocks in Hong Kong by making reference to the findings of a reviewing exercise conducted by different geologists using conventional borehole logging approaches. It aims to quantify the impact due to inconsistent interpretations of RMR parameters and inadequate rock joint descriptions. Suggestions tailored to address these challenges and inconsistencies in evaluating RMR for foundation purposes are presented for discussion.

1. INTRODUCTION

Meta-sedimentary rocks are distributed over several areas of Hong Kong, including Sai Kung and Shatin, but are especially prevalent in the Northern New Territories where the proposed Northern Metropolis development is located. The published geological information (*Sewell et al., 2000*) indicates that the meta-sedimentary rocks in this region can be highly variable in nature and extent. The Northern Metropolis development covers about one-third of the total area of Hong Kong, with a total area of 30,000 hectares. As an essential platform for Hong Kong's integration into the overall development of the Greater Bay Area, the Northern Metropolis development provides new land for the development of the innovation and technology (I&T) industry and is also one of the main sources of future housing land supply. With the Northern Metropolis development underway, there is a growing awareness of the complexity of these meta-sedimentary rocks and how their rock mass and material properties may affect foundation design.



The Code of Practice for Foundations (*BD, 2017*) currently specifies only one category of presumed allowable vertical bearing pressure for meta-sedimentary rocks on horizontal ground or bedrock. This single presumed allowable bearing pressure with a value of 3,000 kPa is considered conservative for all meta-sedimentary rocks as variations could exist among these rocks. The RMR system, originally developed by Bieniawski (Bieniawski, 1973), has been adopted in the GEO Publication No. 1/2006 – Foundation Design & Construction to estimate the allowable bearing pressure for piles and deformation modulus for jointed rock mass with reference to pile loading test data on instrumented piles within different rock types, including meta-sedimentary rocks, in Hong Kong and US (AASHTO, 2012). Recently, AASHTO (2020) introduced a bearing capacity equation for evaluation of base resistance of drilled shafts for cases where the bearing rock can be characterized by Geological Strength Index (GSI) (Turner and Ramey, 2010). It is noted that GSI was first developed based upon an assessment of the lithology, structure and condition of discontinuity surfaces in the rock mass and was estimated from visual examination of the rock mass exposed in surface excavations (Marinos and Hoek, 2000). There are inherent limitations on interpretation of GSI from boreholes.

The use of RMR system for estimating the allowable bearing pressures in meta-sedimentary rocks has gain popularity in recent years. However, practitioners have encountered challenges in accessing the rating of RMR parameters, particularly for meta-sedimentary rocks. These difficulties arise primarily from the inconsistent interpretations of RMR parameters by different practitioners and inadequate rock joint descriptions in borehole logs due to discrepancies between conventional borehole logging practices and the RMR system.

This paper examines the challenges associated with RMR assessment of meta-sedimentary rocks, focusing on two key issues: 1) inconsistencies in the interpretation from different practitioners regarding the rating of RMR parameters, and 2) inadequate rock joint descriptions resulting from discrepancies between conventional borehole logging practices and the requirements of the RMR system. Suggestions to address these challenges when evaluating RMR for foundation purposes will be discussed. These include standardizing the length of the RMR assessment interval and establishing clear principles for assigning ratings to the respective RMR parameters to reduce inconsistencies across practitioners. Additionally, additional details in rock joint descriptions that build upon conventional borehole logging practices is suggested, thereby enhancing the accuracy of RMR assessments. A case study demonstrating the application of a new approach in RMR assessment will be presented, using a drillhole record from the Northern New Territories.

2. META-SEDIMENTARY ROCKS IN THE NORTHERN NEW TERRITORIES OF HONG KONG IN RELATED TO RMR ASSESSMENT FOR FOUNDATION PURPOSE

Meta-sedimentary rocks are found in several areas of Hong Kong, and especially in the Northern New Territories, where they comprise a significant proportion of the solid geology. In the Northern New Territories, the meta-sedimentary rocks distribute generally along the northeast-southwest trending Tuen Mun- Lo Wu Fold Belt, extending from the Heung Yuen Wai area in the northeast to the northern Tuen Mun area in the southwest. The meta-sedimentary rocks in this area mainly belong to the Lok Ma Chau Formation (Cslm and Cslt), with some belonging to the mylonitised sedimentary rocks under Tai O Formation (Jo) and some belonging to the partially metamorphosed sedimentary rocks under Tuen Mun Formation.

According to GEO Publication No. 1/2006, the RMR system is applicable to sedimentary and metamorphic rocks, except for those rock masses affected by dissolution features (e.g. marble formation). As such, massive marble formations belonging to the Yuen Long Formation as well as the marble clastic bearing rocks under the Tuen Mun Formations, are generally not applicable for the RMR assessment.

The meta-sedimentary rocks exhibit complex geological characteristics such as highly variable lithology or rock types, presences of foliation and highly fractured zones, relatively low rock strength in term of Uniaxial Compressive Strength (UCS) and relatively poor rock mass quality. These complexities of metasedimentary rocks bring challenges to not only the foundation engineers but also the logging geologists. In many cases, the borehole log descriptions are not presented with enough details to facilitate a precise RMR assessment. For example, if a 10m section of rock core is being described as “slickensided planar to rough planar” in the borehole log, the RMR assessment will be forced to use a more conservative assumption of “slickensided planar” for roughness rating estimation over the entire 10m of rock core (i.e. roughness rating = 0 for entire 10m). However,

in reality, those “slickensided planar” joints may only occur locally over 2m of the rock core, instead of the entire 10m. In this case, the overall roughness rating of the 10m rock core have been underestimated due to the lack of details about the positions and extent of the “slickensided planar” joints. More details about the inadequate rock joint descriptions for RMR assessment will be discussed in **Section 4**.

3. ROCK MASS RATING (RMR) SYSTEM FOR JOINTED ROCK MASS FOR FOUNDATION PURPOSE IN HONG KONG

The Rock Mass Rating (RMR) system was first developed by Bieniawski in 1973 (Bieniawski, 1973) and has been undergone multiple modifications since then. In addition to Hong Kong, AASHTO (2012) recommended the use of RMR can be used for determination of strength and modulus parameters and allowable bearing pressure for both drilled shaft and spread footing although AASHTO (2020) recently introduced a bearing capacity equation for evaluation of base resistance of drilled shafts for cases where the bearing rock can be characterized by recommended the use of Geological Strength Index (GSI) for estimation of bearing pressures for drilled shafts in rock (Turner and Ramey, 2010). As discussed above, there are inherent limitations on interpretation of GSI from boreholes.

RMR classifies rock mass by using the following six rock mass parameters (Bieniawski, 1974):

- A. Strength of Intact Rock
- B. Rock quality designation (RQD)
- C. Spacing of discontinuities (Joints)
- D. Condition of discontinuities (Joints), which include:

Di: Discontinuity length rating;	Dii: Separation rating;	Diii: Roughness rating;
Div: Infilling (gouge) rating;	Dv: Weathering rating	
- E. Groundwater conditions
- F. Orientation of discontinuities (Joints)

GEO Publication No. 1/2006 recommends calculating the RMR values for the rock mass beneath the piles according to the guidelines outlined in Table 6.4 of that publication. It is important to note that the ratings for discontinuity length (parameter D(i)) and groundwater conditions (parameter E) are fixed in Table 6.4, while the rating for discontinuity orientation (parameter F) is excluded, as these parameters are deemed irrelevant for assessing allowable bearing pressure.

The RMR assessments presented in this paper were calculated according to the recommendations outlined in Table 6.4 of GEO Publication No. 1/2006. An extraction of Table 6.4 of GEO Publication No. 1/2006 is shown in **Figure 1** for ease of reference.

Table 6.4 – Rating Assigned to Individual Parameters using RMR Classification System (Based on Bieniawski, 1989)

(A) Strength of Intact Rock							
Uniaxial compressive strength, σ_c (MPa)	> 250	250 – 100	100 – 50	50 – 25	25 – 5	5 – 1	< 1
Point load strength index, PLI_{50} (MPa)	> 10	10 – 4	4 – 2	2 – 1	σ_c is preferred		
Rating	15	12	7	4	2	1	0
(B) Rock Quality Designation (RQD)							
RQD (%)	100 – 90	90 – 75	75 – 50	50 – 25	< 25		
Rating	20	17	13	8	3		
(C) Spacing of Joints							
Spacing	> 2 m	2 m – 0.6 m	0.6 m – 0.2 m	200 – 60 mm	< 60 mm		
Rating	20	15	10	8	5		
(D) Conditions of Joints							
Discontinuity length ⁽¹⁾	Rating						
Separation	None	< 0.1 mm	0.1 – 1 mm	1 – 5 mm	> 5 mm		
Rating	6	5	4	1	0		
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickenside		
Rating	6	5	3	1	0		
Infilling (gouge)	None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm		
Rating	6	4	2	2	0		
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed		
Rating	6	5	3	1	0		
(E) Groundwater							
Rating ⁽¹⁾	7						
Notes :							
(1) Rating is fixed as the parameter is considered not relevant to the evaluation of allowable bearing pressure of rock mass.							
(2) RMR is the sum of individual ratings assigned to parameters (A) to (E).							

Figure 1: Extraction of Table 6.4 of GEO publication No. 1/2006 for RMR classification System for foundation purpose.

4. CHALLENGES ASSOCIATED WITH RMR ASSESSMENT OF META-SEDIMENTARY ROCKS AND THE CORRESPONDING SUGGESTED POTENTIAL SOLUTIONS

As mentioned in Section 1, the challenges of evaluating the RMR of meta-sedimentary rocks are mainly related to the following reasons:

- 1) inconsistencies in the interpretation of different practitioners regarding the rating of RMR parameters; and
- 2) inadequate rock descriptions in borehole logs due to discrepancies between conventional borehole logging practices and the RMR system.

In addition, it appears that the degree of opening of the joint has been taken into account in both the infilling (gouge) rating assessment (parameter Div) and the separation rating assessment (parameter Dii). Also, the assessment of the roughness rating (parameter Diii) is challenging due to the typically smaller size of rock cores (less than 84 mm), which results in a low reliability.

The challenges associated with each of the RMR parameters (Parameters A to E) as outlined in Table 6.4 of GEO Publication No. 1/2006, along with issues related to the inadequate precision of the borehole logs, are discussed and listed below. Corresponding suggestions for each issue will also be discussed. These include standardising the rock quality detail assessment intervals and the methodology for rating relevant RMR parameters to minimize inconsistencies in interpretation. To address the issue of inadequate rock descriptions in borehole logs, it is recommended to provide additional details to enhance the rock joint descriptions beyond conventional borehole logging practices in order to improve the accuracy of RMR assessments.

4.1. RMR Parameter Related to Strength of Intact Rock

Challenges Related to Difficulties on Obtaining Representative data for Intact Rock Strength

Uniaxial Compressive Strength (UCS) or Point Load Strength Index (PLI50) are essential for assessing the RMR rating for the Strength of Intact Rock (Parameter A). However, the presence of foliations and other discontinuities, such as bedding or fractures, in meta-sedimentary rocks makes it challenging to obtain suitable samples for carrying out the conventional Uniaxial Compressive Strength (UCS) tests and Point Load Tests (i.e.

referring to Diametral Test and Axial Test). Consequently, UCS or PLI50 data (in material failure mode) are not always available to accurately represent the intact rock strength when evaluating the RMR for meta-sedimentary rocks.

Suggestion: Apart from the Diametral Test and Axial Test, ASTM D351-95 (ASTM, 1995) also suggests the Irregular Lump Test as one of the Point Load Tests for determining PLI50. The Irregular Lump Test offers greater flexibility in sample selection, allowing for a greater number of suitable samples to be obtained for determining PLI50 in meta-sedimentary rocks, especially in the presence of foliations and discontinuities. The applicability and practicality of using the results of Irregular Lump Tests for determining intact rock strength in meta-sedimentary rocks should be explored. Further research is required to investigate the correlation between UCS and Irregular Lump Test results, with the aim of establishing the latter as an alternative to the Point Load Test in assessing rock strength.

4.2. RMR Parameter Related to Discontinuities (Joints)

The RMR Parameter B (Rock quality designation (RQD)), Parameter C (Spacing of discontinuities), and the 5 sub-class ratings of Parameter D (Conditions of Discontinuity) reflect the joint characteristics of the rock mass. The challenges and suggestions related to the RMR parameters related to discontinuities are summarised in **Table 1**.

Table 1: Challenges and suggestions related to the RMR parameters related to discontinuities

	Challenge	Suggestion
Rock Quality Designation (RQD) (B)	<p>Drilled cores of metasedimentary rocks are prone to weathering and disintegrate readily due to the prominent foliation. Soon after drilling, the cores tend to obtain high RQD as there are only few joints. After drying for some time, even in term of weeks, the cores may start to disintegrate and become a series of discs leading to a lower RQD.</p>	<p><u>Existing Borehole Logs</u> In general, RQD ratings can be directly obtained from the RQD values listed in the borehole log. Basically, normal RQD logging practice as mentioned in Geoguide 3 shall be followed.</p> <p><u>New Borehole Logs</u> It is suggested carry out logging shortly after drilling so to capture the in-situ property as far as practicable, and obtain the RQD ratings directly from the RQD values listed in the borehole log.</p>
Spacing of Discontinuities (C)	<p>There are various methods used by different geotechnical practitioners to estimate the spacing of discontinuities. For example, some practitioners</p> <ul style="list-style-type: none"> refer to the spacing outlined in the borehole log, as detailed in Table 7 of Geoguide 3 – Guide to Rock and Soil Description use the Fracture Index for their calculations inspect core boxes or analyse core box photographs. <p>These inconsistent practices can lead to differing RMR values for the same borehole.</p>	<ul style="list-style-type: none"> Date obtained from Televiewer Test can be used to estimate the joint spacing and therefore the RMR rating. If televiewer result is not available, the spacing of discontinuities is suggested to be back calculated based on weighted average of the Fracture Index (F.I.) as stated in the borehole log, for an interval of 1 metre or less of intact core pieces with reasonably uniform character, except for those recorded as ‘F.I. >20’ or ‘non-intact’ (NI). The follow equation is used to determine the spacing of joints: $Spacing\ of\ Joint\ (mm) = \frac{1000}{F.I.}$For rock core sections with F.I. logged to be F.I.>20 or NI, RMR rating of 5 should be adopted.
Discontinuity length (Di)	<p>The rating for Discontinuity length is fixed as 2 as per Table 6.4 in GEO Publication No. 1/2006 due to the reason that persistence is considered not relevant to the evaluation of allowable bearing pressure of rock mass.</p>	
Joint Separation (Dii)	<p>The seven (7) descriptive terms for aperture size used in conventional borehole logging practices (Table 9 of Geoguide 3) do not fully align with the five (5) RMR rating classes for Joint Separation outlined in Table 6.4 of GEO Publication No. 1/2006. This may lead to inconsistencies in the interpretation by different practitioners.</p> <p><i>The RMR rating classes for Joint Separation include five categories: None, <0.1 mm, 0.1-1 mm, 1-5 mm, and >5 mm.</i></p> <p><i>The descriptive terms for aperture size defined in Geoguide 3 consist of seven categories: Wide (> 200 mm), moderately wide (60 - 200 mm), moderately narrow (20 - 60 mm), narrow (6 - 20 mm), very narrow (2 - 6 mm), extremely narrow (> 0 - 2 mm), and tight (0mm)</i></p> <p><u>Example:</u></p>	<p><u>Existing Borehole Logs</u></p> <ul style="list-style-type: none"> Refer to borehole log description of aperture size Estimate aperture size based on Table 9 of Geoguide 3 Suggest referring to the upper bound aperture size the descriptive terms as conservative approach <u>Example:</u> Suggest assuming 2mm as the aperture size for “Extremely narrow” <p><u>New Borehole Logs</u></p> <ul style="list-style-type: none"> Indicate exact separation or aperture size in addition to the conventional Geoguide 3 requirements Refer to the separation range as suggested for the RMR Separation Rating <u>Example:</u> Very Narrow (2mm); Extremely Narrow (<1mm)

	Challenge	Suggestion																														
	<p>In RMR calculation, descriptive term "Extremely narrow" (> 0 - 2 mm) fall into the classification of three classes (<0.1 mm, 0.1-1 mm, and 1-5 mm).</p> <p>RMR classification may be interpreted differently by various practitioners, leading to discrepancies in separation rating values that can range from 5 to 1.</p>																															
Roughness (Diii)	<p>The nine (9) descriptive terms for joint roughness in conventional borehole logging practices (Table 8 of Geoguide 3) do not fully align with five (5) RMR rating classes for roughness outlined in Table 6.4 of GEO Publication No. 1/2006. This may lead to inconsistencies in the interpretation by different practitioners</p> <p><i>The RMR rating classes for Joint roughness include five categories: Very rough, Rough, Slightly rough, Smooth, and Slickenside</i></p> <p><i>The descriptive terms for roughness defined in Geoguide 3 consist of nine categories: rough stepped, rough undulating, rough planar, smooth stepped, smooth undulating, smooth planar, slickensided stepped, slickensided undulating, and slickensided planar</i></p> <p><u>Example:</u> The descriptive term "rough undulating" in borehole log could be interpreted as "Very rough", "Rough", or "Slightly rough" by various practitioners in RMR assessment, leading to discrepancies in roughness rating values that can range from 3 to 1.</p>	<table border="1"> <thead> <tr> <th>Descriptive Terms in borehole log as per Geoguide 3</th> <th>Suggested class of RMR roughness rating</th> <th>RMR Rating</th> </tr> </thead> <tbody> <tr> <td>Rough Stepped</td> <td>Very rough</td> <td>6</td> </tr> <tr> <td>Rough Undulating</td> <td>Very rough</td> <td>6</td> </tr> <tr> <td>Rough Planar</td> <td>Rough</td> <td>5</td> </tr> <tr> <td>Smooth Stepped</td> <td>Slightly rough</td> <td>3</td> </tr> <tr> <td>Smooth Undulating</td> <td>Slightly rough</td> <td>3</td> </tr> <tr> <td>Smooth Planar</td> <td>Smooth</td> <td>1</td> </tr> <tr> <td>Slickensided Stepped</td> <td>Slickenside</td> <td>0</td> </tr> <tr> <td>Slickensided Undulating</td> <td>Slickenside</td> <td>0</td> </tr> <tr> <td>Slickensided Planar</td> <td>Slickenside</td> <td>0</td> </tr> </tbody> </table> <p>*Refer to Note [1] for details and elaboration of the suggestions.</p>	Descriptive Terms in borehole log as per Geoguide 3	Suggested class of RMR roughness rating	RMR Rating	Rough Stepped	Very rough	6	Rough Undulating	Very rough	6	Rough Planar	Rough	5	Smooth Stepped	Slightly rough	3	Smooth Undulating	Slightly rough	3	Smooth Planar	Smooth	1	Slickensided Stepped	Slickenside	0	Slickensided Undulating	Slickenside	0	Slickensided Planar	Slickenside	0
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Slickensided Stepped	Slickenside	0																														
Slickensided Undulating	Slickenside	0																														
Slickensided Planar	Slickenside	0																														
Infilling (gouge) (Div)	<ol style="list-style-type: none"> Descriptive terms used in conventional borehole logging practices not fully align with the classifications outlined in Table 6.4 of GEO Publication No. 1/2006. Inadequate descriptions in borehole logs may lead to inconsistencies in the interpretation by different practitioners. <p><i>The RMR rating classes for Joint Infilling include five categories: None, Hard filling <5mm, Hard filling >5mm, Soft filling <5mm, and Soft filling >5mm</i></p> <p><i>Conventional borehole logging practices: typically stated with the material name and used wordings of "stained", "coat" and "infill" to roughly illustrate the thickness of the infilling material.</i></p> <p><u>Example:</u> Descriptive term "chlorite coated" could be interpreted as soft infilling or hard infilling by various practitioners. "Coated" can also be interpreted as <5mm or >5mm in thickness.</p>	<p><u>Existing Borehole Logs</u> <i>For infilling hardness:</i></p> <ul style="list-style-type: none"> In the case of no description on hardness of infilling material, the typical states of the infilling material is suggested to be referred. Suggested RMR Infilling hardness for some of the common infillings are listed as below: <table border="1"> <thead> <tr> <th>Infilling Type</th> <th>Suggested RMR Infilling Hardness Class</th> </tr> </thead> <tbody> <tr> <td>Non-cohesive soil</td> <td>Soft Filling</td> </tr> <tr> <td>Cohesive soil</td> <td>Soft Filling</td> </tr> <tr> <td>Kaolin</td> <td>Soft Filling</td> </tr> <tr> <td>Chlorite</td> <td>Soft Filling</td> </tr> <tr> <td>Calcite</td> <td>Hard Filling</td> </tr> <tr> <td>Manganese</td> <td>Hard Filling</td> </tr> <tr> <td>Quartz</td> <td>Hard Filling</td> </tr> </tbody> </table> <p><i>For infilling thickness:</i></p> <ul style="list-style-type: none"> Suggest referring to the description terms of infilling if no details on infilling thickness in the borehole log. 	Infilling Type	Suggested RMR Infilling Hardness Class	Non-cohesive soil	Soft Filling	Cohesive soil	Soft Filling	Kaolin	Soft Filling	Chlorite	Soft Filling	Calcite	Hard Filling	Manganese	Hard Filling	Quartz	Hard Filling														
Infilling Type	Suggested RMR Infilling Hardness Class																															
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	Challenge	Suggestion
	This lack of details in the borehole log may lead to discrepancies in infilling rating values that can range from 4 to 0.	<ul style="list-style-type: none"> Suggested RMR Infilling thickness for some of the common description terms are listed as below: <ul style="list-style-type: none"> ➢ “No Infill”, “Clean”, and “Stain” as 0mm ➢ “Coating” as <5mm “Infill” as ≥5mm <p><u>New Borehole Logs</u></p> <ul style="list-style-type: none"> Suggest specifying the hardness of the infill (hard or soft) in addition to the standard Geoguide 3 requirements Note the material thickness or refer to the range of infill thickness indicated in the RMR Infilling Rating Descriptive terms “Clean”, “Stain” and “No infill” are considered to indicate infilling in thickness of 0mm <u>Example</u>: Chlorite coated (soft infill, <5mm); Calcite infilled (hard infill, <5mm)
Weathering (Dv) _[2]	The rating for Weathering can be directly obtained from the weathering grading as stated in the borehole log. Basically, normal weathering logging practice as per Geoguide 3 may be followed.	
<p><u>Note [1]:</u></p> <ul style="list-style-type: none"> When consider the RMR Roughness Rating, the first terms of “rough”, “smooth” and “slickensided” in Table 8 of Geoguide 3 are considered representing Joint unevenness (i.e. the small scale roughness), while the second terms of “stepped”, “undulating” and “planar” are considered representing the joint undulation or waviness (i.e. the large scale roughness). The Joint unevenness and Joint waviness are referring to as js and jw in the RMi by Palmström and Q system, with the combination of them representing the overall Joint roughness jR. According to Palmström (2008), the Joint “roughness” under RMR system appears referring generally to the Joint unevenness (i.e. the small scale roughness, js), in which the term “rough”, “smooth” and “slickensided” in RMR system are generally “equivalent” to the terms of “rough planar”, “smooth planar” and “slickensided planar” in the Q system (and hence also Table 8 of Geoguide 3). With that the overall joint roughness jR is the combination of js and jw, it is considered reasonable to imply that the highest rating class of “very rough” should be joint surface which has larger roughness than “rough planar”, which may mean joints described as “rough undulating” and “rough stepped”. On the other hand, the intermediate class of “slightly rough” is considered to be joints with roughness larger than “smooth planar” but worse than “rough planar”, which may be represented by those “smooth undulating” and “smooth stepped” joints. While it is commonly adopted in the conventional borehole logging system, it should, however, be noted that the waviness of joint is originally intended for larger scale roughness measured on a dm to m scale. As such, engineering judgements may be required, and cores should be reviewed where it is considered necessary when using the suggested RMR rating. 		

4.3. RMR Parameter E – Groundwater

The rating for Groundwater is fixed as 7 as per Table 6.4 in GEO Publication No. 1/2006 due to the reason that groundwater is considered not relevant to the evaluation of allowable bearing pressure of rock mass.

4.4. Preciseness of Conventional Borehole logging Descriptions

In addition to the challenges associated with each of the RMR parameters mentioned above, there are also other challenges associated with logging practices for RMR assessment.

Challenge due to Rock Quality Variations at Different Depths Not Indicated Precisely in the Borehole Log:

In conventional borehole logging practices, borehole log descriptions often lack the precise details needed for effective RMR assessment. Specific rock quality characteristics at various positions within the rock cores are

not accurately represented. This is particularly common for joint roughness and joint aperture, which are frequently recorded in broad ranges that span multiple RMR rating classes, rather than being distinctly separated based on their actual observed levels. For example, in **Figure 2**, the cores are described as having “smooth planar, rough undulating” and “very narrow to extremely narrow” joints, with calcite and chlorite coatings extending over 20 meters, from 48m to 68m below ground level (mbgl). However, upon examining the actual cores, “smooth planar” joints were found present only in the upper 10 meters, from 48mbgl to 58mbgl, while the “very narrow” joints are found only in the first 5 meters, from 48mbgl to 53mbgl. In this case, conventional rock description practices are too generalized to provide detailed information on rock quality at specific sections of the core for RMR assessment. As a result, the RMR Ratings Dii and Diii may be interpreted differently by various practitioners. Some might use the lower bound of RMR ratings, while others could opt for an average rating for the entire length of the rock core. This variation may lead to inconsistencies in the overall RMR values.

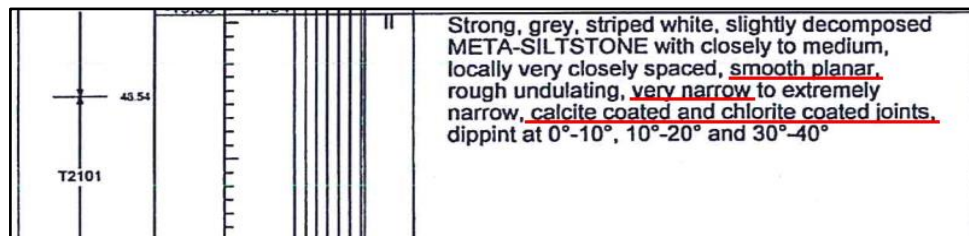


Figure 2: Example of Borehole Logging (from 48mbgl to 68mbgl).

Suggested Solution:

- 1) For **new borehole logs** – When preparing the borehole log, it is recommended that the logging geologist use a 0.5-meter assessment interval to gather detailed information regarding the RMR parameters discussed in **Section 4**. If any differences can be identified within this 0.5-meter interval, it is advisable to separate the logging descriptions accordingly. Using smaller assessment intervals for logging will yield more precise details for RMR evaluation. Additionally, it is recommended to avoid broad descriptive ranges (i.e. >0.5-meter interval), particularly for sections of rock cores for determination of the founding levels. Instead, it is recommended using specific minor descriptions to indicate local observations and to highlight variations in the RMR parameters.
- 2) For **existing borehole logs** – As the description of borehole log may not be precise enough for accurate RMR calculation, a conservative RMR rating is suggested to be adopted for those non-precisely described parameters. For instance, in **Figure 2**, the entire 20m rock core under this major description is suggested to be considered as smooth planar, very narrow joints with calcite and chlorite coated for RMR assessment.

4.5. Multifarious Approaches for Calculating RMR

Challenge due to Multifarious Approaches for Calculating the Overall RMR for Rock core:

It is observed that different practitioners may use different methods to calculate overall RMR for rock cores and the calculated RMR could deviate. Some practitioners may simply do the calculation by averaging certain RMR parameters and use the averaged data to come up with the overall RMR for the rock from the borehole log. Others may separate RMR calculation whenever there is a change in the parameters and then estimate the combined RMR for the relevant rock core length. In **Figure 3**, even though the rock description (rock strength, joint aperture, joint roughness) is the same for the selected rock section (from 47.94mbgl to 50.00mbgl), RMR calculations were conducted separately according to the changes in RMR parameters of fracture index and RQD.

Suggested Solution:

- 1) It is suggested to standardise the RMR calculation approach by calculating RMR separately whenever there is a change in the parameters and then estimate the combined RMR for the relevant rock core length (see the example above in **Figure 3**). Where relevant, RMR calculation is suggested to cover from the engineering rockhead level (*normally category 1(c) or category 2 according to Code of Foundation 2017 (BD, 2017)*) to the end of borehole.

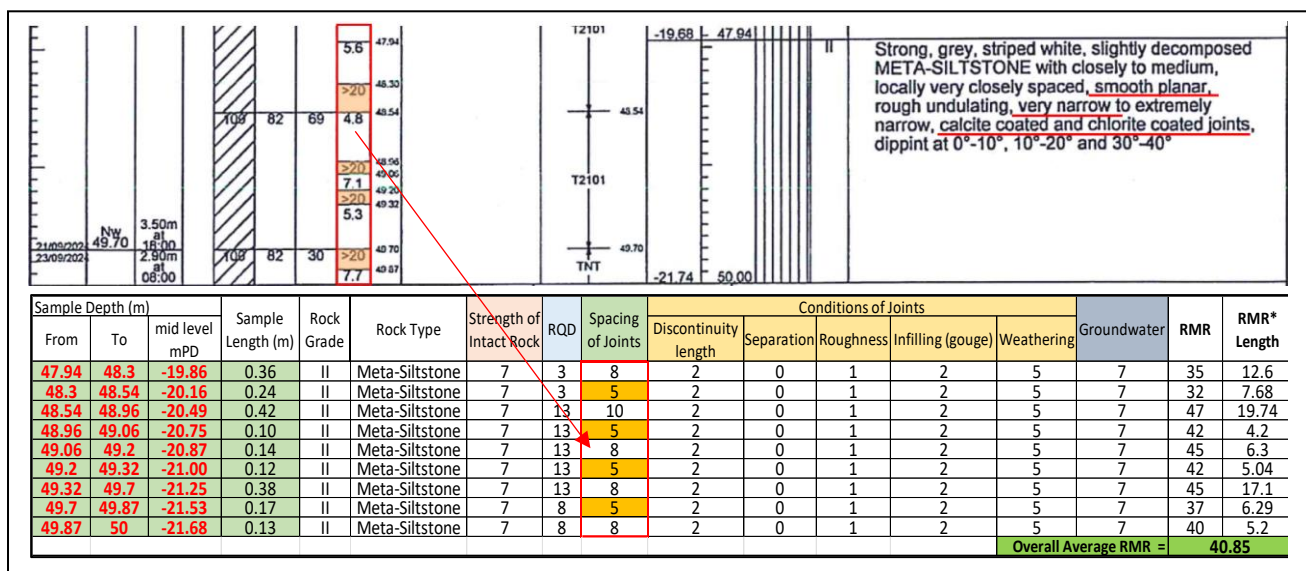


Figure 3: Example of RMR Calculation of Selected Rock Portion (from 47.94mbgl to 50.00mbgl)

5. CASE STUDY – APPLICATION OF THE POTENTIAL SOLUTIONS FOR RMR ASSESSMENT OF META-SEDIMENTARY ROCKS

The potential solutions for RMR assessment as mentioned in Section 4 have been applied to a recently drilled borehole (namely BH-X1 for ease of reference) at a site in the Northern New Territories underlain by meta-sedimentary rocks. During the RMR assessment, it was noted that the log for BH-X1, which was prepared using conventional logging practices, lacked sufficient information to enable an accurate RMR assessment. To facilitate a more precise RMR estimation, the suggestions as mentioned in Section 4 were applied to BH-X1. A comparison of the RMR assessment results before and after the application of the potential solutions are presented below.

5.1 RMR of BH-X1 Before Applying the Potential Solutions

As shown in the part extraction of the log and photos of BH-X1 (from 36.53mbgl to 42.77mbgl) in Figure 4, The descriptions in the log were generic, failing to capture the variations in rock quality at different depths. Thus, a conservative RMR rating was adopted for those non-precisely described parameters (e.g. aperture size of joint and hardness of material infilling at joints). As shown in Figure 5, the average calculated RMR for BH-X1 (i.e. based on conventional borehole logging practices) from 36.53mbgl to 42.77mbgl is 38.73.

5.2 RMR of BH-X1 After Applying the Potential Solutions:

To implement the potential solutions for RMR, the cores of BH-X1 were thoroughly inspected, and the log for BH-X1 was reviewed and updated to include relevant details. The borehole log was then revised according to the “suggestions for new borehole log” as mentioned in Section 4, aiming to provide a detailed and precise description fitting the RMR classification system, thereby facilitating the RMR assessment. Additional observed details have been included to illustrate the variation in rock qualities at different depths. For example, a more detailed description of joints aperture size ranged from 1-2mm between 36.93mbgl and 40.20mbgl as well as soft manganese oxide coated at rough planar joints from 39.91mbgl to 40.20mbgl were added. The additional precise details in the revised log of BH-X1 are highlighted in red in Figure 6 for the part extraction of the revised log of BH-X1.

RMR assessment has been conducted again using the revised borehole log by the same practitioner according to the new guideline as proposed in Section 4. With a more detailed and precise description, the average calculated RMR on revised borehole log (from 36.53mbgl to 42.77mbgl) was increased by more than 10%, from 38.73 to 43.16. Part extraction of the RMR calculation from 36.53mbgl to 42.77mbgl is shown in Figure 7.

Figure 8 displays the calculated RMR results plotted against depth (meters below ground level) for the original borehole log of BH-X1, which was obtained using conventional logging methods, alongside the revised borehole log that incorporates the potential solutions as discussed in **Section 4**. It can be observed from **Figure 8** that the revised borehole log generally exhibits a larger RMR value. This may be due to adoption of a more conservative approach for those non-precisely described parameters in the borehole log, which lacks detail regarding variations in rock quality at different depths.

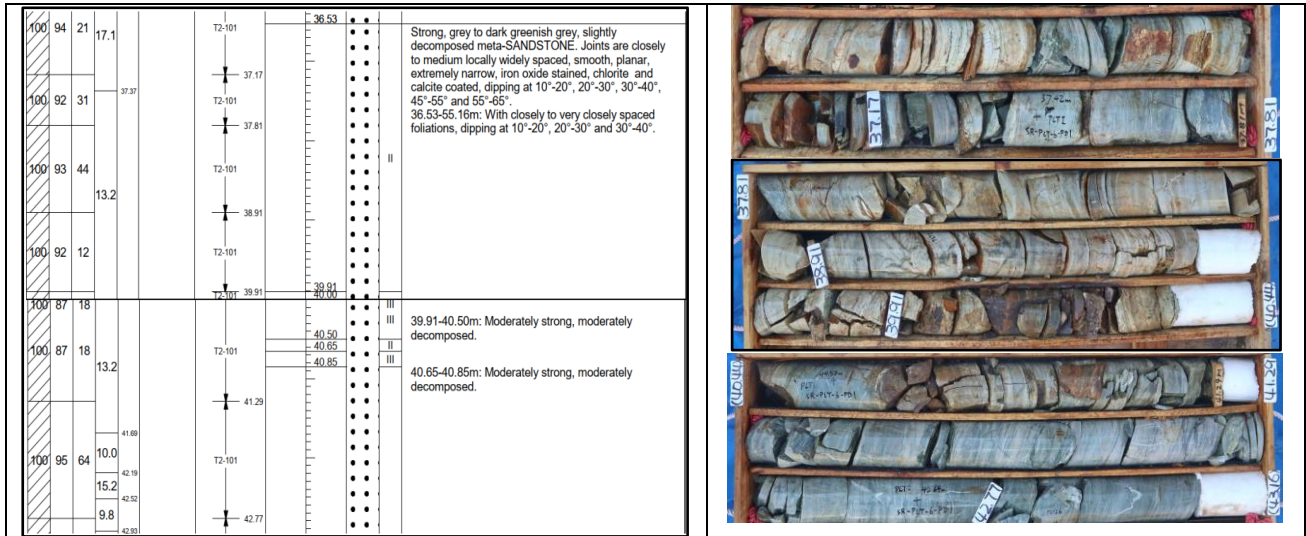


Figure 4: Part Extraction of BH-X1 (from 36.53mbgl to 42.77mbgl) and the corresponding core box photos

Sample Depth (m)		Sample Length (m)	Rock Grade	Strength of Intact Rock	RQD	Spacing of Joints	Conditions of Joints					Groundwater	RMR	RMR* Length*	
From	To						mid level mPD	Discontinuity length	Separation	Roughness	Infilling (gouge)				Weathering
36.53	37.17	12.03	0.64	II	7	3	5	2	1	1	2	5	7	33	21.12
37.17	37.37	11.61	0.20	II	7	8	5	2	1	1	2	5	7	38	7.6
37.37	37.81	11.29	0.44	II	7	8	8	2	1	1	2	5	7	41	18.04
37.81	38.91	10.52	1.10	II	7	8	8	2	1	1	2	5	7	41	45.1
38.91	39.91	9.47	1.00	II	7	3	8	2	1	1	2	5	7	36	36
39.91	40.5	8.68	0.59	III	4	3	8	2	1	1	2	3	7	31	18.29
40.5	40.65	8.31	0.15	II	7	3	8	2	1	1	2	5	7	36	5.4
40.65	40.85	8.13	0.20	III	4	3	8	2	1	1	2	3	7	31	6.2
40.85	41.29	7.81	0.44	II	7	3	8	2	1	1	2	5	7	36	15.84
41.29	41.69	7.39	0.40	II	7	13	8	2	1	1	2	5	7	46	18.4
41.69	42.19	6.94	0.50	II	7	13	8	2	1	1	2	5	7	46	23
42.19	42.52	6.53	0.33	II	7	13	8	2	1	1	2	5	7	46	15.18
42.52	42.77	6.24	0.25	II	7	13	8	2	1	1	2	5	7	46	11.5
												Average RMR	38.73		

Figure 5: Part Extraction of RMR Calculation of the BH-X1

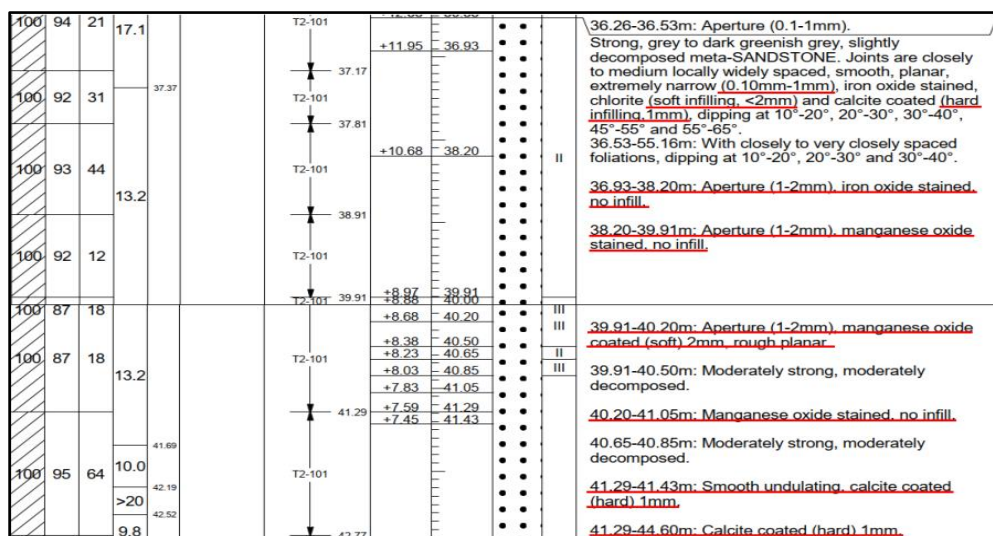


Figure 6: Part Extraction of Revised Borehole Log for BH-X1 for RMR Assessment

Sample Depth (m)			Sample Length (m)	Rock Grade	Strength of Intact Rock	RQD	Spacing of Joints	Conditions of Joints					Groundwater	RMR	RMR* Length
From	To	mid level mPD						Discontinuity length	Separation	Roughness	Infilling (gouge)	Weathering			
36.53	36.93	12.15	0.40	II	7	3	5	2	4	1	2	5	7	36	14.4
36.93	37.17	11.83	0.24	II	7	3	5	2	1	1	6	5	7	37	8.88
37.17	37.37	11.61	0.20	II	7	8	5	2	1	1	6	5	7	42	8.4
37.37	37.81	11.29	0.44	II	7	8	8	2	1	1	6	5	7	45	19.8
37.81	38.2	10.88	0.39	II	7	8	8	2	1	1	6	5	7	45	17.55
38.2	38.91	10.33	0.71	II	7	8	8	2	1	1	6	5	7	45	31.95
38.91	39.91	9.47	1.00	II	7	3	8	2	1	1	6	5	7	40	40
39.91	40.2	8.83	0.29	III	4	3	8	2	1	5	2	3	7	35	10.15
40.2	40.5	8.53	0.30	III	4	3	8	2	4	1	6	3	7	38	11.4
40.5	40.65	8.31	0.15	II	7	3	8	2	4	1	6	5	7	43	6.45
40.65	40.85	8.13	0.20	III	4	3	8	2	4	1	6	3	7	38	7.6
40.85	41.05	7.93	0.20	II	7	3	8	2	4	1	6	5	7	43	8.6
41.05	41.29	7.71	0.24	II	7	3	8	2	4	1	2	5	7	39	9.36
41.29	41.43	7.52	0.14	II	7	13	8	2	4	3	4	5	7	53	7.42
41.43	41.69	7.32	0.26	II	7	13	8	2	4	1	4	5	7	51	13.26
41.69	42.19	6.94	0.50	II	7	13	8	2	4	1	4	5	7	51	25.5
42.19	42.52	6.53	0.33	II	7	13	5	2	4	1	4	5	7	48	15.84
42.52	42.77	6.24	0.25	II	7	13	8	2	4	1	4	5	7	51	12.75
													Average RMR	43.16	

Figure 7: Part Extraction of RMR Calculation of the Revised Borehole Log for BH-X1

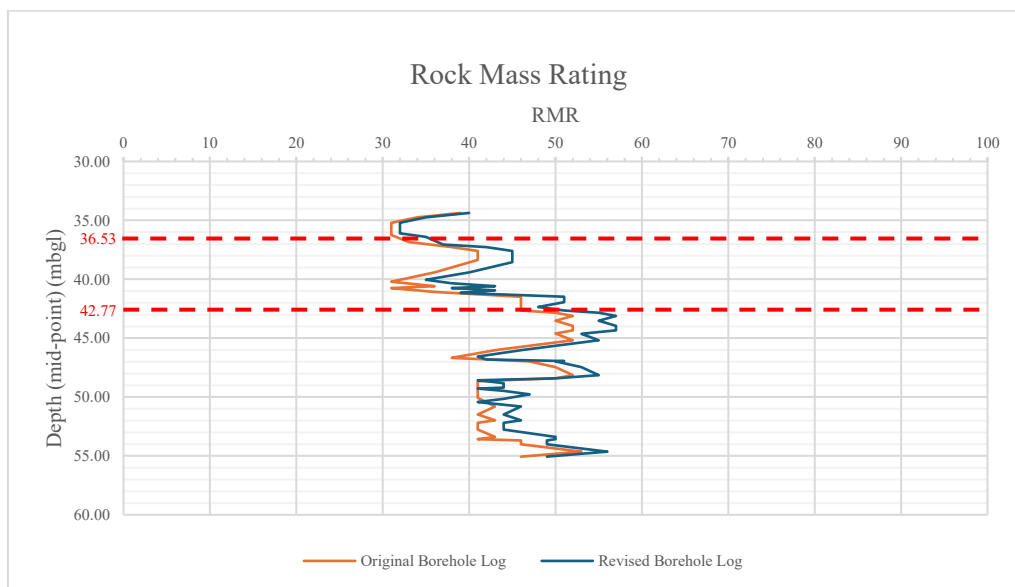


Figure 8: Comparison of Calculated RMR using Original Borehole Log and Revised Borehole Log pf BH-X1

6. SUMMARY

When using the RMR classification system to assess rock mass quality for foundation design, inconveniences often arise with borehole records generated through conventional borehole logging practices. These challenges primarily stem from inconsistencies in the evaluation of RMR parameters by different practitioners, as well as misalignments between conventional borehole logging methods and the RMR system. This issue is particularly pronounced in the case of meta-sedimentary rocks, which exhibit significant variability in rock mass quality. To address these challenges, solutions specifically designed to enhance RMR assessments have been proposed. These suggestions include the standardisation of the RMR parameter rating calculation and the improvement of conventional borehole logs to provide more detailed information, thereby facilitating a more representative RMR assessment.

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