ROCK STRENGTH AT THE CORING INTERFACE

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ABSTRACT
Boreholes in rock usually involve drilling to practical tungsten carbide bit refusal and then changing the drilling technique to rock coring. Often this change is used as an indication of a change in rock weathering or strength. Before the commencement of rock coring the SPT result would typically be to refusal. After obtaining the rock core, point load index tests are used to classify the rock strength. This paper examines the validity of the usual assumption of a change in rock property at this drilling interface. The results show that a drilling interface does not necessarily translate into a geological interface or change in rock properties. The current definition of SPT refusal level in rock is shown to be inadequate, and the strength interpretation of such tests in rock is dependent on the rock type and defects of the rock.

1 INTRODUCTION
The Standard Penetration Tests (SPT) is discontinued when a total of 30 blows cause less than 100 mm penetration or no measurable penetration occurs (Australian Standards, 1993). The limitations of stopping the SPT at 30 blows in the seating drive for rock material was discussed in Look (1997). The commencement of rock coring occurs shortly after SPT refusal and practical tungsten carbide bit refusal. Many borehole reports show a “jump” in classification at the interface as the change in drilling technique to rock coring is often viewed as also a change in classification, e.g. Extremely Weathered (XW) to Distinctly Weathered (DW) or very low strength to medium strength, etc.

While there is some dependence on the drilling rig and drilling techniques used, nature does not usually have a pronounced transition for the same geological material unit. For the same material there is a transition from one zone to another rather than the line on the borelog, which represents a geological model rather than a geological reality. The drilling supervisor can provide a more accurate description from the rock core rather than the SPT sample or non-cored drilling just above, especially if wash boring techniques are being used to advance the boreholes. Therefore the material just above the start of coring is conservatively assumed to be a weaker grade of material. This is an implicit assumption in many borelogs produced. Rock core samples are then used to carry out the visual strength classification, point load index testing and other types of testing.

In some instances rock coring is not carried out and drilling is stopped at SPT or drilling refusal. This paper therefore examines the more reliable rock core test results and compares with the SPT results near that interface with the aim to:

• Assess if the usually inferred change in rock strength does occur at that drilling interface i.e. is drilling interface = geological interface and
• Determine the relationship between SPT values and rock strength.

2 BACKGROUND CONSIDERATIONS
Clayton (1995) provides the following relationship between the unconfined compressive strength (UCS) and the corrected SPT value ($N_{60}$) for weak rocks.

$$\text{UCS} \geq 10 \times N_{60} \text{ (kPa)}$$  (1)

Broch and Franklin (1972) describe the point load index test and provided empirical relationships between the index and uniaxial compressive strength (Equation 2). Broch and Franklin (1972) also recommend the strength classification from extremely low to very high based on the point load index testing, and this classification has been adopted in the Australian Standards (1993) for Geotechnical Site Investigations.

$$\text{UCS} = 24 \times I_s(50)$$  (2)

Therefore, if Equations 1 and 2 were valid, then one would expect

$$I_s(50) \geq 10 / 24 \times N_{60} \text{ (kPa) = 0.4 } N_{60} \text{ (kPa) or 0.4 } \times 10^{-3} \times N_{60} \text{ (MPa)}$$  (3)

When tested for reasonableness then some values seem unrealistic. Only the “greater than” part of the equation provides some comfort to the values obtained. For example:
• A very low strength rock (Is(50) = 0.03 to 0.1 MPa) requiring an SPT in the range 72 to 240 seems reasonable, however,
• A high strength rock (Is(50) > 1.0 MPa) requiring an N value of 2400 seems unreasonable.

Look and Griffiths (2001 and 2004) have shown that UCS / Is(50) ratio of 5 to 17 generally applies for the rocks in South East Queensland and that data at the rock drilling interface was extended to incorporate the SPT N value used in this analysis. Therefore, assuming Equation 1 is still valid and using the local data, then Table 1 provides the corresponding relationships for the rocks in South East Queensland.

Table 1: Strength relationships between various tests.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>UCS - Is(50) ratio</th>
<th>Is(50) - N_{60} (MPa) relationship</th>
<th>Strength Classification from Is(50) values derived from SPT N Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>From the Standard Ratio</td>
<td>24</td>
<td>1_{s} (50) &gt; 0.4 \times 10^{-3} N_{60}</td>
<td>(V. Low +) (Low +)</td>
</tr>
<tr>
<td>General (Brisbane rocks)</td>
<td>11*</td>
<td>1_{s} (50) &gt; 0.9 \times 10^{-3} N_{60}</td>
<td>(V. Low +) (Low+) (Medium +)</td>
</tr>
<tr>
<td>Tuff</td>
<td>18</td>
<td>1_{s} (50) &gt; 0.6 \times 10^{-3} N_{60}</td>
<td>(V. Low +) (Low +)</td>
</tr>
<tr>
<td>Phyllite</td>
<td>5</td>
<td>1_{s} (50) &gt; 2.0 \times 10^{-3} N_{60}</td>
<td>(Low +) (Medium +)</td>
</tr>
<tr>
<td>Greywacke / Argillites</td>
<td>8</td>
<td>1_{s} (50) &gt; 1.2 \times 10^{-3} N_{60}</td>
<td>(Low +) (Medium +)</td>
</tr>
</tbody>
</table>

* Varies from 12 to 9 for the Is(50) values in the axial and diametral direction, respectively

Table 1 is based on the assumption of the validity of Equation 1. This is subsequently shown to be invalid. Table 1 however serves to highlight that different rock types would have different strength implications for the same SPT value e.g. an SPT of 400 could be a medium strength phyllite but a low strength Tuff. Note that even with an N value of 400 (usually inferred), a high strength rock has not been achieved using Equation 1, and in the case of the standard 24 ratio usually applied, the rock is still low strength to even an N value of 700.

3 DATA ANALYSIS

Data from sites in the South East and central Queensland region, described in Look and Griffiths (2001 and 2004), have been tabulated to assess any relationship between the point load index strengths and the standard penetration tests. The inferred SPT was used by directly converting to a 300 mm standard penetration and the Is(50) data within 1 metre of the SPT refusal was tabulated. The total relevant 89 data points from the 150 boreholes initially tabulated covered the following rock types:

• Sandstones / Siltstones (19 data points)
• Tuff (10 data points)
• Phyllites (16 data points)
• Greywackes / Argillites (38 data points)
• Conglomerate (5 data points)
• Mudstone (1 data point)

The latter 2 rock types were generally excluded as insufficient data in the analysis of rock type trends or showed up as outliers in the trend analysis. The rock weathering on which the point load testing was carried out was predominantly Distinctly Weathered (DW) but 17 of the data points were Slightly Weathered (SW). In almost all cases the SPT refusal rock just above was classified as a weathering grade lower. In many cases the classification was Highly Weathered (HW) before the start of coring and Moderately Weathered (MW) for the cored samples. In order to establish trends the data was sorted into:

• Defects
• Rock Types
• SPT N Values ranges

The analysis process involved starting with the total number of data points and progressively removing outliers until a reasonable regression correlation was obtained. In many of the Tables below the strength range and SPT values have been extrapolated nominally beyond the data points for completeness only.

3.1 DEFECTS

When considering the effects of defects on the rock strength, the linear trend analysis resulted in a very poor correlation. Improved (but only marginally OK) correlation was obtained with exponential trends. Figure 1 shows all the 89 data
points with 19 and 70 data point for defects less than or equal to 60 mm and greater than 60 mm, respectively. These relationships are not considered meaningful.

When the outlier points are removed the relationship improves significantly (Figure 2). Where the defects are less than 60 mm the correlation begin to show some meaningful relationship. Conversely when defects are greater than 60 mm the correlation is weak. Table 2 provides the strength classification evident from this relationship. The approximate UCS / N value ratio based on the general UCS / Is(50) ratio in Table 1 is also shown.
Table 2: Rock Strength assessment from the SPT N Value (simplified)

<table>
<thead>
<tr>
<th>Strength Is(50) (MPa)</th>
<th>SPT N Value</th>
<th>Approximate UCS (kPa) / N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Defects &lt;= 60 (mm)</td>
<td>Defects &gt; 60 (mm)</td>
</tr>
<tr>
<td>Extremely Low to Low</td>
<td>&lt; 0.3</td>
<td>&lt; 125</td>
</tr>
<tr>
<td>Medium</td>
<td>0.3 – 1.0</td>
<td>125 – 250</td>
</tr>
<tr>
<td>High</td>
<td>1.0 – 3.0</td>
<td>250 – 350</td>
</tr>
<tr>
<td>Very to Extremely High</td>
<td>&gt; 3.0</td>
<td>&gt; 350</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This is for all rock types examined in this analysis, and N values above 350 have been extrapolated beyond the data points shown. This limitation should be kept in mind.

3.2 ROCK TYPES

When the data is sorted into the various rock types, the limited data shows that any SPT value in tuff should be disregarded, as a negative relationship is evident (Figure 3). This may suggest that at the drilling interface where this data was obtained that some significant change in rock properties could be occurring. This correlates with the general observation that the tuff has less of a weathering profile. The SPT in sandstone / siltstone provides the best correlation for the rock types in this analysis. Table 2 can then be refined for the various rock types as shown in Table 3. Note that this provides a picture different from the previous SPT values used for strength based on defects only.

Table 3: Rock Strength assessment from the SPT N Value for various rock types (simplified).

<table>
<thead>
<tr>
<th>Strength</th>
<th>Is(50) Value (MPa)</th>
<th>Phyllite Sandstones / Siltstones Greywacke / Argillites Tuff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely Low to Low</td>
<td>&lt; 0.3</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Medium</td>
<td>0.3 – 1.0</td>
<td>100 – 200</td>
</tr>
<tr>
<td>High</td>
<td>1.0 – 3.0</td>
<td>100 – 200</td>
</tr>
<tr>
<td>Very to Extremely High</td>
<td>&gt; 3.0</td>
<td>&gt; 200</td>
</tr>
</tbody>
</table>

Table 3 also shows that the relationships of Table 1 would be generally incorrect by a factor of 4 to 5 and by an order of magnitude for Equation 3. This data does not agree with Equation 1. Using local relationships of Table 3 then Equation 1 may be valid for extremely low to low strength values only i.e. UCS less than 3 MPa. Above this value the exponential nature of the trend line shows the estimation of UCS from a linear relationship would be significantly underestimated. The approximate UCS / N value ratio based on the UCS / Is(50) ratio for the various rock types provided in Table 1 is shown in Table 4.

The summary results of Table 3 should be read with the understanding of the limitations summarized in Table 5. The outlier points were progressively removed until an “optimum” relationship was obtained. In the case of the tuff, the removal of any outlier points resulted in a further decrease in the strength of the relationship. The approximate percentage of points neglected provides an indication of the reliability of typical data obtained.

Table 4: UCS / SPT N Value ratio for various rock types (simplified).

<table>
<thead>
<tr>
<th>Strength</th>
<th>Is(50) (MPa)</th>
<th>Phyllite Sandstones / Siltstones Greywacke / Argillites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely Low to Low</td>
<td>&lt; 0.3</td>
<td>50</td>
</tr>
<tr>
<td>Medium</td>
<td>0.3 – 1.0</td>
<td>30 – 50</td>
</tr>
<tr>
<td>High</td>
<td>1.0 – 3.0</td>
<td>50 – 75</td>
</tr>
<tr>
<td>Very to Extremely High</td>
<td>&gt; 3.0</td>
<td>75</td>
</tr>
</tbody>
</table>

Table 5: Limitation of data set used in the Rock Strength assessment for various rock types.

<table>
<thead>
<tr>
<th>Data Used</th>
<th>Phyllite Sandstones Greywacke / Argillites Tuff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of Points</td>
<td>16</td>
</tr>
<tr>
<td>Data Points with outliers removed</td>
<td>12</td>
</tr>
<tr>
<td>% Neglected</td>
<td>25%</td>
</tr>
</tbody>
</table>
3.3 SPT N VALUES

Figure 4 shows the SPT data sorted with all values and then with the outliers removed. The data is then sorted into SPT values less than 100, greater than 100 and greater than 120. This data shows that SPT N values less than 100 have little relevance in terms of its relationship to strength data. SPT N values above 120 are generally 12 times much more reliable than N values less than 100.

The regression correlation coefficient of 0.44 suggests that there is a high degree of scatter of results even after removing the obvious outliers. This may be due to the following factors:

- The Is(50) test represents an intact strength (undi sturbed) while the SPT produces a disturbed test.
- The Is(50) results represent both axial and diametral results

The results suggest that in order to use the SPT values with confidence the strength classification should be known before. This seems to be contradictory as the intent is to use the SPT result to obtain the strength classification. However there are instances when rock core samples are available to suggest the strength classification and additional data from the SPT can then be used to refine the design.

4 CONCLUSIONS

Data from various geotechnical reports in different rock type in south east Queensland was analysed to show:

- An SPT value in rock has little engineering significance unless qualified in terms of the rock type, defects or a prior knowledge of the rock strength classification. For example an SPT of 200 could mean a medium strength rock with defects less than 60 mm or a low strength rock with defects greater than 60 mm. The value of 200 could also indicate a high strength phyllite or a low strength greywacke.
- SPT values are most reliable in the sandstone and siltstone and meaningless in tuff. This may indicate that for tuff there is a sudden change in rock strength / weathering with drilling technique change, while for the other rock types the change is a more gradual transition.
When the relationship of UCS ≥ 10 N_{60} (kPa) is used with UCS = 24 Is(50), meaningless values result at higher values due to the exponential fit trend lines. Local relationships provided more meaningful results, but only for rocks classified as low strength and would fit only a lower bound line for the data used herein. Therefore when used with local UCS / Is(50) ratios the following relationships were more applicable and avoid the errors associated with a simple linear extrapolation of one trend line

- UCS ≥ 20 N_{60} (kPa) extremely low to low strength rocks (SPT < 200),
- UCS ≥ 30 N_{60} (kPa) medium strength rocks,
- UCS ≥ 40 N_{60} (kPa)… high strength rocks (SPT > 200)
- UCS ≥ 50 N_{60} (kPa)… very to extremely high strength rocks

This seems to be contradictory, as the intent is to use the SPT result to obtain the strength classification. This means that to be useful in design the rock cores must first be suitably classified in terms of strength before being able to use the numerical SPT value in design. Due to the method of derivation the above relationship provides the intact rock strength UCS value while the SPT N value represents a disturbed value.

- The data showed that an inferred SPT extrapolation less than 100 had little relevance to strength for engineering design and only values above 120 show some correlation with strength. To be relevant the SPT refusal in rock should therefore be defined as 40 blows / 100 mm penetration in the test drive. This is higher than the Australian Standard of 30 blows / 100 mm penetration at any stage of the drive, i.e. seating or test drive.

### 5 REFERENCES