

Role of defects in rock mass classification

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Abstract

Despite the advancement of the sophisticated numerical modelling techniques used to estimate rock mass strength, rock mass classification still remains as one of the key inputs and fundamental tools for rock mass characterisation, especially in the early stages of project development. A challenge faced by practitioners who use rock mass classification schemes is the appropriate description and incorporation of rock mass defects—especially those outside the category known as ‘open joints’. This paper discusses the author’s experiences with various techniques used to describe and assess such defects.

1 Introduction

Rock mass classification is one of the fundamental tools for rock mass characterisation, especially in the early stages of project development. More sophisticated techniques such as Synthetic Rock Mass (SRM) have been used increasingly in modelling rock mass behaviour, but require equally sophisticated input data which cannot always be obtained during the early stages of the project. Also, developing discrete fracture network (DFN) models and further applying the SRM approach is always time-consuming; and currently only a limited number of people can service the needs of the industry. Furthermore, it is the author’s experience that without calibration of such models to specific sites, the uncertainty in the predictive capability of such approaches is still relatively high.

One of the challenges faced by practitioners who use rock mass classifications is the appropriate conversion of inherently variable geological characteristics into engineering values or categories. Incorporation of rock mass defects, especially those outside the category of ‘open joints’ is probably the main challenge. Most of the current mainstream rock mass classification systems do not explicitly account for rock block defects other than open joints; and one is forced to include the other defects into that category, or ignore them. In 2001, Laubscher’s Mining Rock Mass Rating (MRMR) classification system (Laubscher and Jakubec, 2001) introduced the rock block strength concept and suggested a method to capture and incorporate defects other than open joint defects. It is not an objective of this paper to discuss Laubscher’s MRMR in detail; but rather, to illustrate the impact of defects on rock mass strength estimates and discuss some of the challenges of techniques to collect data.

2 Geotechnically significant types of rock defects

Brittle deformation of rocks and/or sedimentation processes introduce defects that have variable geometry, continuity, shear strength, and cohesion. Such defects could significantly reduce the rock block or rock mass strength, especially in an unconfined situation. It is typical industry practice, when describing a drill core, to call fractures that do not have bonding cement ‘open joints’ (Figure 1). The special categories of ‘open’ defects are small discontinuous fractures or micro fractures. However, rock defects can change their strength characteristics with time and location. For example, open joints invaded by hydrothermal fluids could become ‘cemented’ with minerals (Figure 2); and similarly, mineral cement could be leached out of joints by ground water flow. Special categories of ‘cemented defects’ are mineral veins and veinlets such as those on copper porphyries.

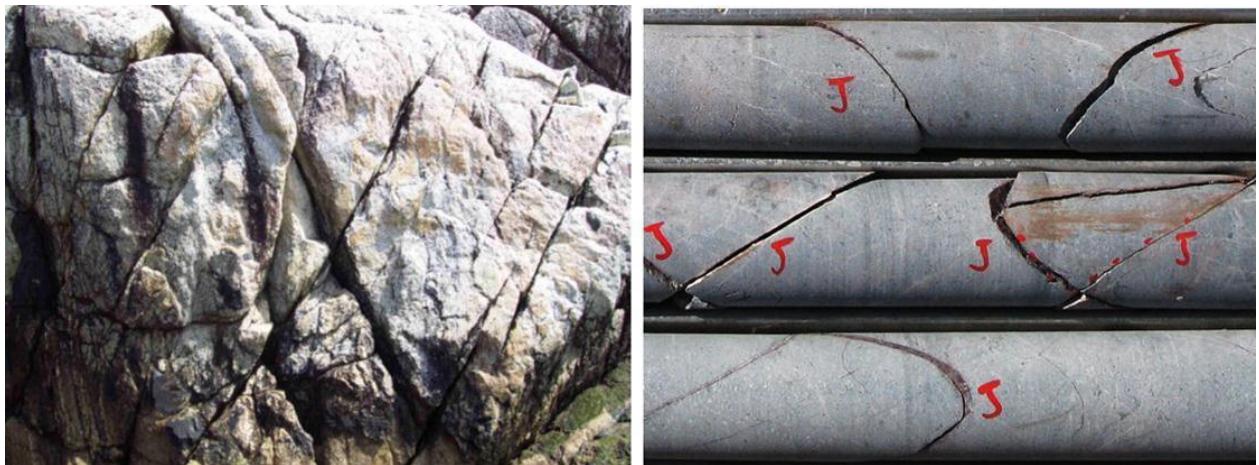


Figure 1 Examples of continuous, block forming, and discontinuous joints in the rock outcrop (left) and in the drill core (right)

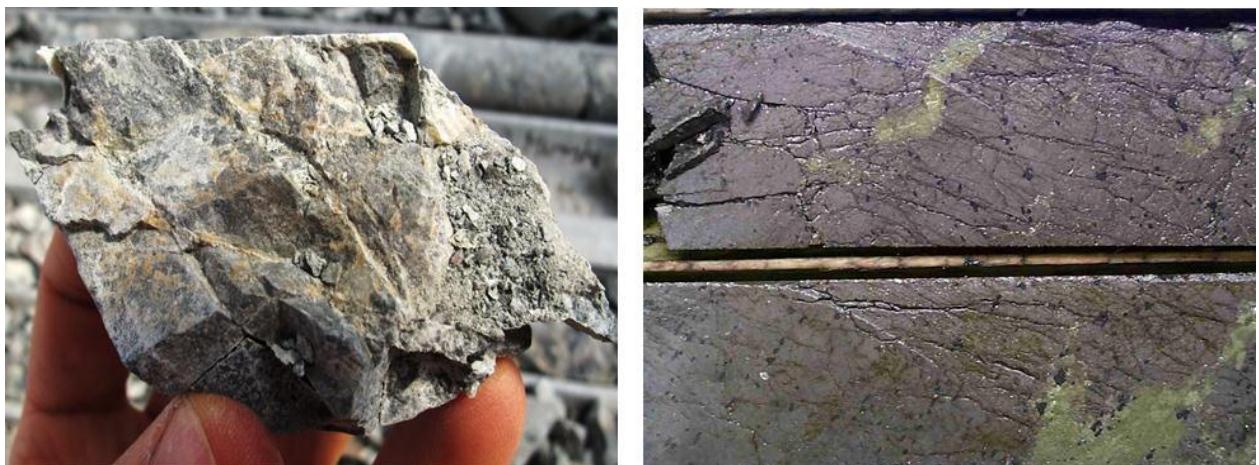


Figure 2 Types of small scale defects. In the example on the left, small fractures in rocks, small fractures significantly reduce the rock block strength while relatively strong micro defects 'survived' core cutting (right)



Figure 3 Types of brittle deformation fractures cemented by gypsum in the rock block and in the core from Northparkes Mine in Australia

Rock that has been foliated (Figure 4) or sedimentary rocks which have well-developed bedding planes typically exhibit high strength anisotropy and are very challenging to describe using classification systems.



Figure 4 Highly foliated metamorphic rock in this example from Aljustrel Mine in Portugal is still very strong and exhibits relatively low strength anisotropy



Figure 5 The bedding planes in sedimentary rocks from Congo show moderate rock mass strength reduction (left), but very low strength near the fault (right)

3 Data collection comments

This section discusses some of the challenges and pitfalls of data collection. Although many aspects of data collection are similar for core logging and mapping, this paper focuses on core logging; since, when the rock exposures are available, more sophisticated methods such as SRM could be employed to develop rock mass strength and understand rock mass behaviour.

The biggest challenge in geotechnical core logging is the fact that we cannot see the rock mass in a three-dimensional large scale. Hence, defect continuity, large scale geometry, and orientation cannot be well understood. It is also difficult, especially in laminated or bedded rocks, to separate drill-induced damage from natural joints and open fractures. A third issue is drill hole orientation bias. It is necessary that core logging results and exposure mapping (if available) are correlated (Figure 6) and, if necessary, conversion factors developed.

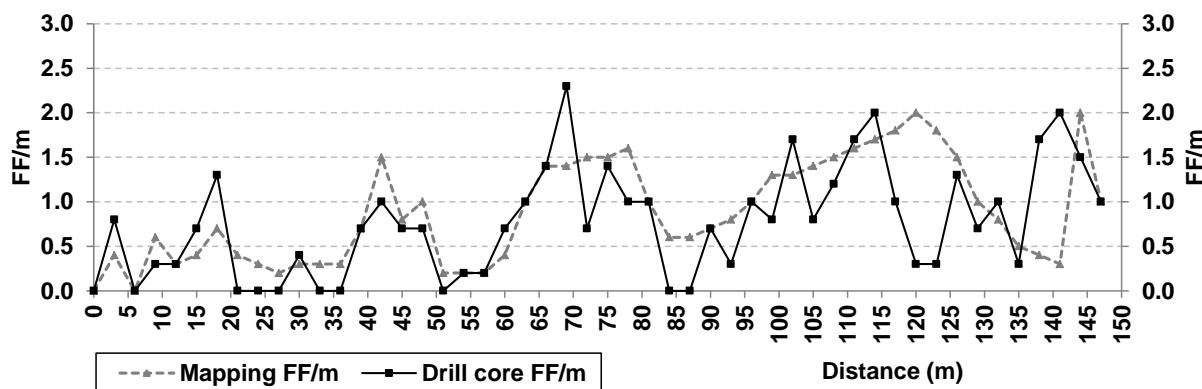


Figure 6 Example of good fracture frequency correlation between the cross cut mapping (dashed line) and drill core logging from Chuquicamata Mine in Chile

It is important not to 'double dip' when estimating intact rock strength (IRS). If micro defects are numerous and small, they are usually already taken into consideration when testing the core; there should be no further adjustment. If, however, the selected core samples for testing are from zones without micro defects, the resulting IRS must be adjusted. It is sometimes difficult to see micro fracturing, and wetting the core can help to identify it. Also, precipitation of secondary minerals can reveal the otherwise 'invisible' defects (Figure 7).



Figure 7 Precipitated secondary minerals reveal the degree of micro fracturing in Chilean porphyry and moisture enhanced micro fracturing from E 48 mine in Australia

When large sets of laboratory or point load testing are available, it is often possible to observe bimodal distribution of the unconfined compressive strength results. This could be caused by impact of micro defects on core strength and may provide guidance for estimating the strength of the defects. In fact, laboratory testing should be designed in such a way that the quantity and strength of micro defects are evaluated.

The other approach is to observe how the rock breaks using hammer blow or drop tests. It is the author's experience that the drop test, when performed correctly, yields more consistent results than the hammer blow test, especially when several different people are involved in logging the core. The drop test consists of dropping the core on a firm pad (e.g. a concrete floor) in a consistent manner from the same height; and then tabulating how many core breaks occur on defects and how many occur through intact rock. Simple categories can then be developed, for example:

1. Always breaks on defect.
2. Sometimes breaks on defect.
3. Seldom/never breaks on defect.

This provides a visual estimate of micro defect strength (Figure 8); which, in combination with laboratory test results, can yield a better field estimate of IRS.



Figure 8 Examples of high density of micro defects. The defects in the photo on the left, although numerous, have no effect on IRS; while defects in the photo in the middle and on the right dramatically reduce IRS

It is sometimes difficult to separate mechanically induced breaks from natural breaks and a number of criteria, such as mineral coating, break surface characteristics, etc., can help to correctly classify the core. There is always a reason why certain sections of the core have more mechanical breaks than others, given the same drilling conditions. Again, making note of these reasons and investigating them could lead to a better understanding and sub-domaining of the rock mass. It is always recommended to log and visually plot all breaks next to natural joints (Figure 9). An example in Figure 9 illustrates that fault zone 1 has many natural open joints while fault zone 2 has mainly mechanical breaks due to weakened rock by alteration.

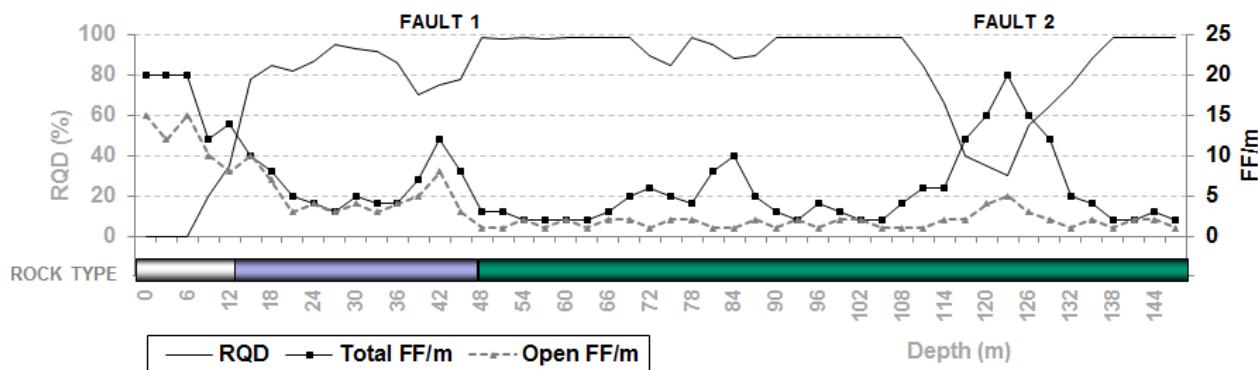


Figure 9 Plot of natural open joint frequency, total fracture frequency and RQD

The same applies to cases of foliation or bedding planes; these should also be plotted separately from open joints, so the anisotropy of in situ rock mass rating can be calculated, with or without taking bedding planes or foliation into consideration.

4 Intact rock, rock block and rock mass concept

Current mainstream rock mass classification systems do not explicitly account for the rock block defects other than open joints. However, as illustrated in the section above, certain rock types contain variable quantities of other defects that may or may not impact the rock block and rock mass strength. If the rock mass is to be accurately characterised, it is necessary to take such defects into consideration.

The IRMR/MRMR classification system by Laubscher and Jakubec (2001) recognises and addresses this need to include all important defects in rock mass classification. The concept of strength adjustment to rock block and rock mass has been developed and introduced to the practice (Figure 10).

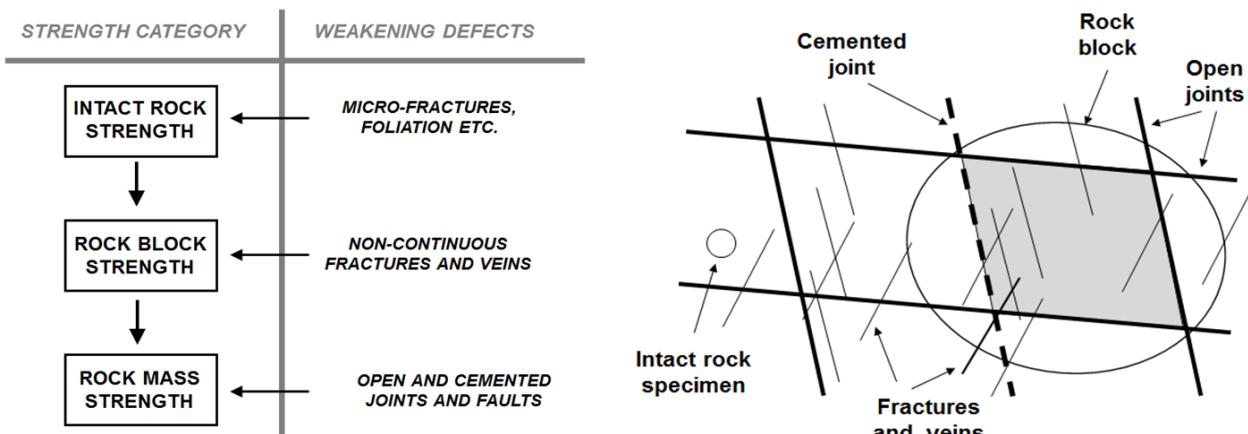


Figure 10 Scale concept used in Laubscher's IRMR/MRMR classification system

It should be noted that besides accounting for the rock block defects and cemented joints, one of the other differences between Laubscher's MRMR system and several other classifications is the use of RQD. While RQD is still a very fast and effective method of assessing rock mass competency, it can be used only in a narrow range of fractured rock masses. The downside of using RQD (and classification systems which include RQD) in poor as well as in good quality rocks is illustrated in Figure 11.

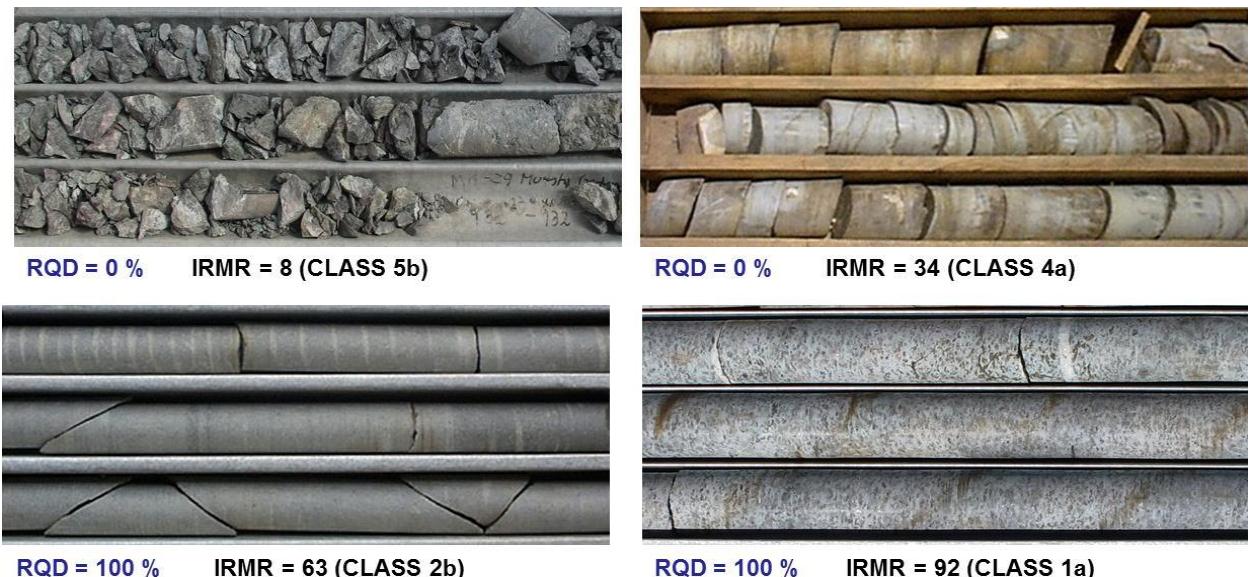


Figure 11 Problems with RQD and classification systems that include RQD

While both examples on the top row of Figure 11 have RQD = 0, they offer significantly different mining and ground support environments. Similarly, the two rock masses in the bottom row have RQD = 100%, but both would have significantly different caveability and resultant fragmentation.

Any classification system only provides guidelines, and cannot capture the inherent variability of nature. It is up to us, the geologists, geotechnical engineers, and mining professionals, to use our skills and judgement to observe and develop an understanding of the rock mass characteristics and behaviour. A good, recent example of such work was from El Teniente Mine (Brzovic and Villaescusa, 2007), where a geotechnical data collection system was adjusted to the specifics of the primary copper ore in order to correctly assess the rock mass.

5 Experiences from recent studies

One of the first practical outcomes after the introduction of rock block strength was on fragmentation analyses for block caving operations. A paper on the impact of defects was presented at the International Workshop on Rock Mass Classification in Underground Mining by Jakubec and Esterhuisen (2007). The concept of rock block strength (RBS) was included in Block Caving Fragmentation (BCF) software and the impact of rock block defects was assessed. In 2011, those fragmentation predictions were compared to fragmentation curves developed by Itasca using an SRM approach at Chuquicamata Mine; a close correlation between both methods was obtained (Figure 12).

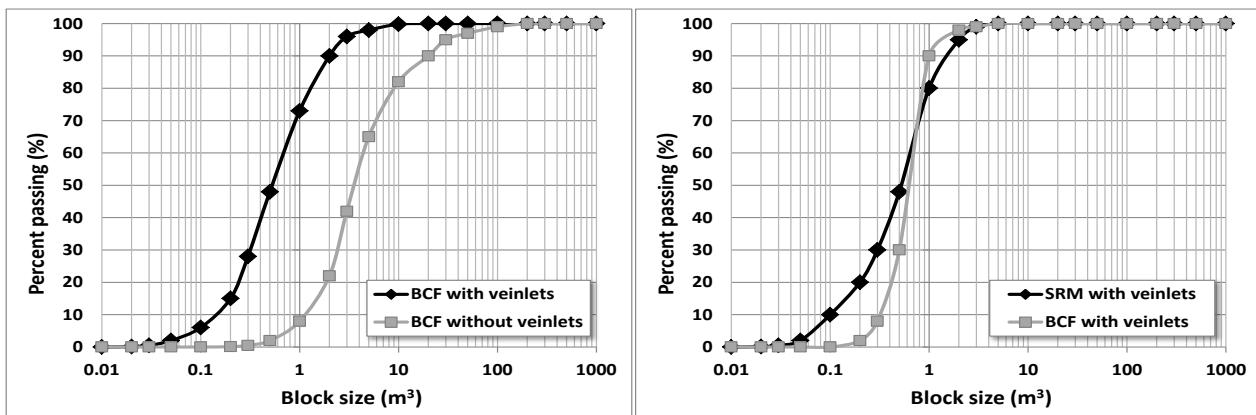


Figure 12 Comparison of primary fragmentation cumulative curves with and without defects using BCF method (left) and comparison of primary fragmentation curves using SRM and BCF approach (right)

As mentioned earlier, the SRM approach was used to better characterise the impact of defects on rock mass strength on several projects including Chuquicamata Mine in Chile (Jakubec et al., 2012). Micro-defected samples were selected from the core and tested in uniaxial compression, along with intact samples. As the shear strength of the micro defects decreased from very strong quartz infilled veinlets, to weaker calcite or anhydrite veinlets, to non-filled fractures, the UCS of the sample decreased as the defect strength became dominant. Additionally, the UCS and the post-peak brittleness and residual strength rises with variability in veinlet strength (Figure 13).

For comparison purposes, the Hoek and Brown size-strength relationship and estimates of rock block strength using Laubscher and Jakubec (2001) methodology were also plotted.

Figure 13 illustrates intact laboratory strength for cases where the veinlet strength is 50 and 25% of the intact rock shear strength. The SRM simulations for rock block strength fall between the Laubscher and Jakubec estimates and the laboratory-produced means for micro-defected samples.

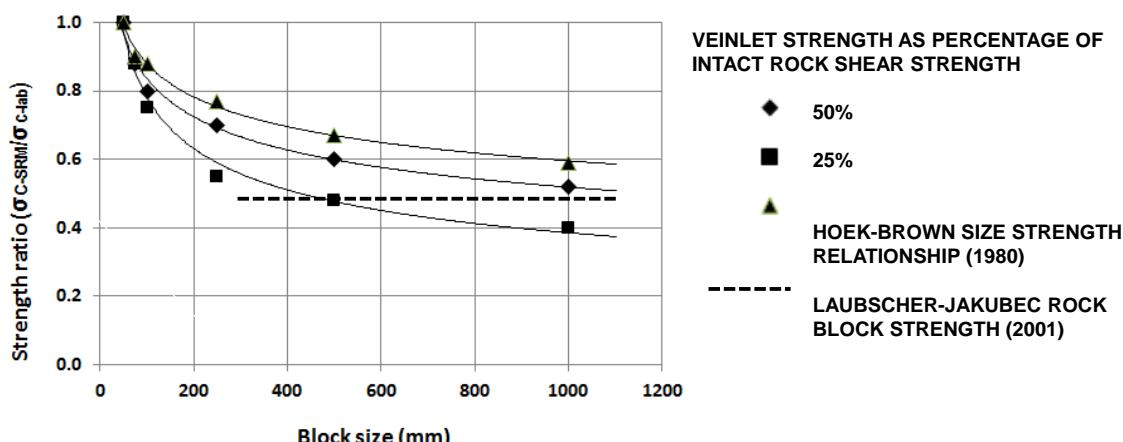


Figure 13 Ratio of SRM-estimated rock strength

These results offer the conclusion that the rock block strength of the micro-defected orebody alterations would be approximately 40–45% of the laboratory-intact UCS values for the Chuquicamata orebody.

6 Concluding remarks

New, exciting, and sophisticated methods to assess rock mass strength are being introduced to the industry. However, it is the author's experience over the past decade or two that the accuracy of input data for such models, based on core and outcrop observations, is not improving. In fact, it is argued that with more time spent on computer models and virtual reality and less time spent in the field, data quality is getting worse. What appears to be missing is crucial engineering judgment. Sadly, it has been experienced on several projects that the rock mass characterisation is far from accurate because practitioners have chosen a methodology that does not take into account many important rock features. In order to benefit from better, more sophisticated, modelling techniques we have to ensure that input data reflects reality.

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