Comparison of Borehole Discontinuity Data Collection Methods – Uncertainty and Quality Concerns

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Abstract
Discontinuity data measured from twelve orientated boreholes was made available by a client for an open pit investigation. On plotting the data stereographically it became obvious that there was something wrong with it since most of the pole data exhibited a “starfish” pattern indicating that the alpha angles had been measured to the nearest 5° and the beta angles to the nearest 10°. The odd appearance of the contoured stereonets also caused concern about the manner in which the data had been collected. A study of the core photographs established that in some cases there seemed to be more than one reference line drawn on the core, and the reference line “barbs” appeared to point up – and down – hole. Because it was not possible to contact the geologist who had originally logged the core it was decided to re-examine the core, establish how the core had been orientated during drilling and make some sample measurements to compare against the data provided. After discussions with the drilling contractor it was determined that the larger diameter core through the weaker overburden material was oriented using a spear and crayon to mark the bottom of the core. A Reflex Act electronic orientation tool was used for the smaller diameter core, and a point marked on the top of the core, from which a reference line could be drawn and discontinuity measurements made.

Unfortunately, most of the borehole core had been left laid out in the field, so that in the six month period between the holes being drilled and re-examined, most of the markings and reference lines drawn on the core had been lost due to the effects of the sun and elements. The core from three boreholes which had been stacked could however be examined. In addition to the problems mentioned above, it was clear that the reference line did not always correlate with the survey instrument mark at the end of each core run; it was not clear whether the reference line corresponded with the top or bottom of the core; in some cases the upper apical trace of the discontinuity ellipse had been measured rather than the lower one; and it was clear that sealed foliations had been logged as discontinuities. Because of the concerns with the reliability of the discontinuity measurements, optical and acoustic televiewers were used to measure the discontinuities directly from the drilled boreholes, and the results compared with the original data. In some of the boreholes there was a good correlation between the measurements, but in others there was not.

1 Introduction
Discontinuities are planes of weakness that frequently control the stability of rock masses. The orientation of discontinuities is one of the most important characteristics considered in the design of any engineering structure or excavation face. Therefore a reliable knowledge of the true orientations of these structures is often required. Orientation data of discontinuities can be measured directly from surface mapping or obtained indirectly from boreholes. Although each of these methods are accompanied with their own particular limitations and advantages, the borehole methods are considered to be associated with a comparatively higher degree of uncertainty since it involves more complex measuring procedures, thus increasing the risk for errors.
In this case study, the discontinuity data was originally obtained from logging orientated boreholes and later using optical and acoustic televiewers. Stereographic analysis of the logged discontinuity data raised a concern that the representative orientation of the discontinuities was not accomplished. A study of the core photos and the site investigation revealed many inconsistencies and inaccuracies in the manner in which the data had been collected. The odd “starfish” patterned stereographic plot in conjunction with the evidence from the core photos contributed substantially to the uncertainty and poor quality of the original discontinuity data set. Subsequent comparisons between the televiewer data and the original data showed good correlations between some boreholes, but poor correlations in other boreholes.

2 Discontinuity orientation measurements

Discontinuity data from twelve orientated boreholes were made available by the client for an open pit investigation. These had previously been logged by other personnel from another consulting company.

2.1 Data uncertainty and quality concerns

A study of the core photos showed errors in the manner in which the data was collected. The errors identified are predominantly associated with the reference line from which the discontinuity alpha and beta angles are measured. As a result of uncertainty associated with this reference line, the original orientation data was considered to be unreliable. Typical problems identified during the core photo study included: more than one reference line, reference line barbs points both up- and down-hole and the reference line was offset from the end of core mark (refer to Table 1).

A subsequent site investigation that allowed measurements to be checked suggested that most of the alpha and beta angles were correct, however a significant percentage of the measurements checked were different. The alpha angles were different by a maximum of 10°. In some of the cases, it appears that the upper apical trace of the discontinuity ellipse was measured rather than the lower one, which means that the beta angles were out by 180°. Using the measured alpha and beta angles to determine which line was actually used to take the measurements from, established that it was not always the same line being used.

After discussions with the drilling contractor, it was discovered that two methods had been used to mark the orientation of the core. A spear or crayon was used to mark the bottom of the larger diameter core and a Reflex Act electronic orientation tool had marked the top of the smaller diameter core, thus increasing the confusion about the reference line from which the discontinuity measurements were made.

The reference mark at the end of the core run was rarely visible; therefore the “correct” reference line was not clear. In addition, the core from some of these holes had been left in their trays laying on the ground at their collar positions, rather than being stacked. The sun and sand had bleached or abraded most of the markings from the core, making the checking of alpha and beta angles impossible. These observations further contributed to the uncertainty associated with the original data set.

2.2 Stereographic interpretation

The stereographical pole plot based on the orientation data from the boreholes displayed an odd “starfish” pattern indicating that the alpha angles had been measured to the nearest 5° and the beta angles to the nearest 10°, as shown in Figure 1. This “starfish” pattern indicated a lack of precision during data collection (Priest, 1993; Holcombe, 2008).

As a result of the doubt about whether the reference line drawn on the core represents the top or the bottom of the core, there were two possible solutions for the calculations of the dip and dip directions of the discontinuities. The contour plot for the data assuming the reference line was on the top of the core is shown in Figure 2 and Figure 3 shows a similar plot assuming the reference line was on the bottom of the core.
Table 1. Summary of the errors detected on core photos.

<table>
<thead>
<tr>
<th>Representative Core Photo</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image 1" /></td>
<td>Some sections of the core had two reference lines marked along their length, approximately 130° apart. In some cases, three reference lines were marked and these were 60° apart and between 30° and 90° apart. Since the core could not always be pieced together to provide a continuous run of core, it was not always possible to know which line was the “correct” one.</td>
</tr>
<tr>
<td><img src="image2.png" alt="Image 2" /></td>
<td>On a number of occasions two consecutive pieces of core had reference line “barbs” pointing in opposite directions. In some cases the “barb” on the reference line pointed down-hole, in some cases up-hole.</td>
</tr>
<tr>
<td><img src="image3.png" alt="Image 3" /></td>
<td>Reference line not correlating with survey instrument mark at end of core run.</td>
</tr>
</tbody>
</table>
Figure 1. Stereographic pole plot showing “starfish” pattern due to the low precision of measurements.

Figure 2. Contour concentration plot showing boreholes for Zone 1, assuming reference line on top of core.
Figure 2 shows a higher concentration of poles, but they tend to be congregated in one main orientation (20°/123°). Figure 3 has lower pole concentration contours, but five discontinuity sets can be identified: 43°/098°, 86°/161°, 86°/067°, 86°/106° and 77°/026°. It was more likely that Figure 3 is a better representation of the discontinuity sets within the rock mass.

3 Comparison of televiewer data with the original data

As a result of the above mentioned reservations about the discontinuity measurements there were concerns about using the data as the basis of the kinematic analysis for the open pit design. In an attempt to obtain some reliable data, optical and acoustic televiewers were employed to collect discontinuity measurements directly from the drilled boreholes and were compared with the original discontinuity data.

Comparison of the discontinuity data obtained from the televiewer logs and from the original discontinuity orientation data revealed that for some drillholes there was a good correlation between the measurements and in other there was not. An example of the good correlation between the original discontinuity data and the televiewer data is illustrated by the contour plots shown in Figures 4 and Figure 5 respectively. There appears to be a reasonable correlation between the data and the stereonet plots for the two sources of structural data. However, comparison of Figures 6 and 7, together with other drillholes show that the two sources of data produce quite different stereoplots.
Figure 4. BH1 – Original data contour plot.

Figure 5. BH1 – Televiewer data contour plot.
Figure 6. BH2 – Original data contour plot.

Figure 7. BH2 – Televiewer data contour plot.
The stereonets for the discontinuities identified during the original orientated core logging and from the latest televiewer data, for all the drillholes, showed that more drillholes for which the two sets of data do not correlate, than those that do correlate. The televiewer data tends to have less steeply dipping discontinuities than the original data set. There is generally a flat lying set, plus a set with a dip ranging from 40 - 60° and a dip direction varying between 075° and 120°.

The discontinuity data for each of the drillholes have been analysed separately in order to determine the major joint sets to be used for the pit design. Comparison of the major joint sets identified from the original discontinuity data and the televiewer data suggests that there is a similarity between some of the sets, despite the apparent difference between some of the stereonets. The correlation between the joint sets identified is summarized in Table 2.

Table 2. Correlation between major joint sets identified.

<table>
<thead>
<tr>
<th>Joint ID</th>
<th>Dip Range (°)</th>
<th>Dip Direction Range (°)</th>
<th>Joint ID</th>
<th>Dip Range (°)</th>
<th>Dip Direction Range (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Original Data</td>
<td></td>
<td></td>
<td>Televiewer Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J1</td>
<td>16 – 68</td>
<td>168 – 238</td>
<td>J1</td>
<td>0 – 39</td>
<td>180 - 270</td>
</tr>
<tr>
<td>J3</td>
<td>19 – 58</td>
<td>056 – 129</td>
<td>J2</td>
<td>0 – 48</td>
<td>079 - 153</td>
</tr>
<tr>
<td>J5</td>
<td>83 – 90</td>
<td>158 - 195</td>
<td>J7</td>
<td>60 – 90</td>
<td>175 - 205</td>
</tr>
<tr>
<td></td>
<td>80 – 90</td>
<td>338 – 015</td>
<td>J9</td>
<td>63 – 82</td>
<td>217 – 229</td>
</tr>
</tbody>
</table>

4 Conclusions

The reliability of the data was questioned because of the concerns regarding its accuracy and precision. The lack of accuracy is due to the confusion over which reference line the measurements were made from, whether the reference line represents the top or bottom of the core, and because the reference line “barb” seems to be pointing both up- and down-hole. Although the televiewer data showed some correlation with the original discontinuity data, the confidence level of the data was inadequate for a detailed open pit design. The recommendation to possibly solve this problem would be to remove the plugs from the holes, determine whether they were still open throughout their length and use a televiewer to measure the discontinuities downhole.

This case study demonstrates the many errors that can be expected if quality control and assurance are not incorporated whilst collecting orientation data and how this adversely affects the subsequent design process. The uncertainty associated with the original discontinuity was too high to confidently use for any detailed design. The design based solely on the low confidence original discontinuity data would be too conservative to be economic.

The core orientation data is a valuable source of structural information for any engineering application, therefore an improvement in collection methods is of great importance. There are many methods that are currently used for core orientation, each with different orientation tools and levels of accuracy. A proper understanding of these methods and their limitations, in conjunction with the ground conditions can improve accuracy and the quality of
data obtained. For example, the traditionally used core stub method makes use of a spear to mark the “bottom of the hole” position which can be problematic when the rock is either too hard or too soft to take a mark from the impacted spear. If the material is very hard, the spear could potentially not leave a mark or bounce across the surface leaving multiple marks, thus making interpretation difficult. Most spears commonly have attachments that can be substituted for a crayon or pencil that would make a better mark on hard material than the spear point, however the driller has to possess the knowledge of when to use the pencil or steel point and be able to judge and control the impact speed of the spear. The orientation methods that use template tools can eliminate the above mentioned problems associated with spears, however these template tools are only suitable if the core stub is irregular and like the spears is not applicable to crumbly core. The more recent core barrel method which makes use of both pencils and templates is claimed to be a more sophisticated method that significantly improves the levels of accuracy and reliability. This method makes use of both mechanical and or electronic tools to determine the gravity vector, however errors are possible if the core at the base of the barrel has been displaced unknowingly during drilling before the core can be lifted. This can result in largely mismatched bottom of hole reference lines between adjacent core runs, thus making the measurements incorrect. This method has been shown to be more successful with good core orientation handling practices and quality assurance controls (Marjoribanks, 2010).

5 References

