Some Results of Quantitative Analysis of Fracture Orientation Distribution along the Segment Tien Yen-Mui Chua of Cao Bang-Tien Yen Fault Zone, Quang Ninh Province, Viet Nam

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Abstract: The results of quantitative analysis of fracture orientation distribution according to the pair of stereonet windows among 05 different survey sites along the segment Tien Yen-Mui Chua, belong to Cao Bang-Tien Yen fault zone, Quang Ninh province, Viet Nam showed that, the correlation values are over 0.80 corresponding to 50%, over 0.75 corresponding to 30% and over 0.65 corresponding to 20%. These values are quite consistent with over 60% of the fracture number in the direction of NW-SE. Especially, the compatibility is clearly reflected in the determination of the frequency of fracture measurements within the division intervals of 20 degrees for dip direction and 10 degrees for dip angle at 05 different survey sites.

Key words: Correlation coefficient, fracture orientation, stereonet windows, dip direction, dip angle.

1. Introduction

A structural unit of rockmass is characterized by the distribution of the parameters of density, orientation, distance, shape of fracture and fault. In some previous studies on geotechnical engineering, the division of the structural units was conducted by using the method of quantitative correlation of fracture distribution [1-3].

Recently, studies [4-6] have used the correlation method to analyse the frequency of fracture orientation distribution which occurred along the tunnel and borehole to identify structural domain boundary. The obtained results from these studies have provided a useful tool to support for determining structural domain unit and delineating structural domain boundary.

In this study, we continue analyzing the fracture orientations at 05 different survey sites along the segment of Tien Yen-Mui Chua, belong to Cao Bang-Tien Yen fault zone, Quang Ninh, Viet Nam using the method of quantitative correlation to confirm its effectiveness for studying structural domain or fault zone.

The Cao Bang-Tien Yen Fault Zone (Fig. 1) is located in the north of Viet Nam, has NW-SE orientation, from Cao Bang province to Cai Bau island, Quang Ninh province, parallel to Song Hong Fault Zone, with 250 km long. This fault traced a line very clearly on the satellite image and topography. The studies of tectonic activity of this fault zone were major implemented by Vietnamses geologists [7-10].

2. Methodology

This study uses the correlation method to caculate correlation coefficient of fracture frequency between two stereonet windows of two different survey sites. The calculation is carried out based on the number of fracture poles in each cell on stereonet window which plotted on the lower hemisphere projection (Fig. 2).
Some Results of Quantitative Analysis of Fracture Orientation Distribution along the Segment Tien Yen-Mui Chua of Cao Bang-Tien Yen Fault Zone, Quang Ninh Province, Viet Nam

Fig. 1  Location map of Cao Bang-Tien Yen fault zone, Quang Ninh province, Viet Nam.

Fig. 2  Stereonet countour poles of two survey sites (two stereonet windows).

The Fig. 2 shows the fracture frequencies on two stereonet windows. After plotting fracture orientations of each survey site on the stereonet window in Fig. 2, the calculation of fracture correlation coefficient between two stereonet windows is carried out by using Eq. (1).

\[ R(x, y) = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}} \]  

Eq. (1)
Some Results of Quantitative Analysis of Fracture Orientation Distribution along the Segment Tien Yen-Mui Chua of Cao Bang-Tien Yen Fault Zone, Quang Ninh Province, Viet Nam

where: \((x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)\) are \(n\) pairs of observations of a random sample of two random variables \(x\) and \(y\); \(\bar{X}\) and \(\bar{Y}\) are the average values of fracture number of two stereonet windows, while \(x_i\) is the fracture number which appears in each cell of the first window and \(y_i\) is the fracture number which appears in each cell of the second window. The values of \(x_i\) and \(y_i\) may lie within 324 cells in each window if each cell is divided into \(10^\circ \times 10^\circ\) according to dip direction and dip angle. The correlation coefficient expresses the strength of the association between the two variables from two stereonet windows. These values always lie within \((-1, 1)\) and they are independent of the magnitude of the variables. If the correlation coefficient is -1, it means perfect negative correlation; if the correlation coefficient is 0, it means no correlation and if the correlation coefficient is 1, it means perfect positive correlation.

3. Results of the Quantitative Calculation of Fracture Orientation Distribution

The quantitative calculation of fracture distribution is conducted according to their frequency at 05 different survey sites on the Jurassic sedimentary rocks of Hacoi formation [11], along the segment of Tien Yen-Mui Chua, belong to Cao Bang-Tien Yen fault zone, Quang Ninh province, Viet Nam, with the length of about 15 km (Fig. 3).

![Fig. 3 Location map of the fracture survey sites along the segment of Tien Yen-Mui Chua, belong to Cao Bang-Tien Yen fault zone.](image)
Along the fault zone, the sedimentary rocks are heavily broken due to tectonic activity. VanChinh Vu [9, 10] suggested that there are at least two tectonic activity phases which happened in Cenozoic Era on Cao Bang-Tien Yen fault zone, whilst the first phase is left-lateral motion which occurred within Oligocene-Miocene period with the sub-horizontal compression direction and the second is right-lateral motion which occurred within Quaternary period with the sub-meridian compression direction.

The fractures are collected at each survey site including entire fracture orientations to ensure objectivity among them. The total fracture number at each survey site is recorded in Table 1.

The determination of quantitative correlation of fracture distribution among survey sites according to pairs of stereonet windows is shown in Fig. 4.

In Fig. 4, although the frequency of fracture measurements on lower hemisphere projection is not completely focused on certain sets, but the high correlation coefficient (Table 2) among them still indicates that they are affected by similar geodynamic conditions.

The correlation values among different survey sites in Table 2 indicate that there are 50% fracture correlation coefficient is over 0.80; 30% fracture correlation coefficient is over 0.75 and 20% fracture correlation coefficient is over 0.66. The high correlation values of fractures among survey sites in Table 2 imply that these survey sites belong to a fault zone and to be affected by similar geodynamic condition.

Besides, the analytical results of total fracture measurements at 05 survey sites by combining and plotting them on the graph of Fig. 5a and b also indicated that there are more than 60% fracture measurements in the direction of NW-SE.

The fracture correlation among different survey sites is also shown by the frequency of fracture number which occurs within the division intervals of 20 degrees for dip direction and 10 degrees for dip angle at 05 survey sites (Fig. 6).

In Fig. 6, the frequency of the fracture number distribution according to dip direction (a) and dip angle

### Table 1  Location of survey sites and their fracture numbers.

<table>
<thead>
<tr>
<th>No</th>
<th>Survey site</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Geological age</th>
<th>Fracture number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QN-01</td>
<td>107° 23' 50.5&quot;</td>
<td>21° 19' 17.7&quot;</td>
<td>J1-2 hc2</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>QN-02</td>
<td>107° 24' 02.2&quot;</td>
<td>21° 19' 09.5&quot;</td>
<td>J1-2 hc2</td>
<td>101</td>
</tr>
<tr>
<td>3</td>
<td>QN-03</td>
<td>107° 25' 19.9&quot;</td>
<td>21° 18' 26.0&quot;</td>
<td>J1-2 hc2</td>
<td>153</td>
</tr>
<tr>
<td>4</td>
<td>QN-04</td>
<td>107° 26' 08.7&quot;</td>
<td>21° 18' 01.9&quot;</td>
<td>J1-2 hc2</td>
<td>101</td>
</tr>
<tr>
<td>5</td>
<td>QN-05</td>
<td>107° 27' 01.4&quot;</td>
<td>21° 17' 20.5&quot;</td>
<td>J1-2 hc2</td>
<td>095</td>
</tr>
</tbody>
</table>

![Stereonets](image1.png)

![Fracture correlation](image2.png)
Some Results of Quantitative Analysis of Fracture Orientation Distribution along the Segment Tien Yen-Mui Chua of Cao Bang-Tien Yen Fault Zone, Quang Ninh Province, Viet Nam

Fig. 4 Fracture correlation coefficient among pairs of survey sites along the segment of Tien Yen-Mui Chua, belong to Cao Bang-Tien Yen fault zone.
Table 2  Fracture correlation coefficient among pair of survey sites.

<table>
<thead>
<tr>
<th>No</th>
<th>Window one</th>
<th>Window two</th>
<th>Fracture correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QN-01</td>
<td>QN-05</td>
<td>0.7879</td>
</tr>
<tr>
<td>2</td>
<td>QN-05</td>
<td>QN-04</td>
<td>0.8819</td>
</tr>
<tr>
<td>3</td>
<td>QN-04</td>
<td>QN-03</td>
<td>0.6671</td>
</tr>
<tr>
<td>4</td>
<td>QN-03</td>
<td>QN-02</td>
<td>0.8941</td>
</tr>
<tr>
<td>5</td>
<td>QN-01</td>
<td>QN-02</td>
<td>0.7566</td>
</tr>
<tr>
<td>6</td>
<td>QN-05</td>
<td>QN-03</td>
<td>0.8438</td>
</tr>
<tr>
<td>7</td>
<td>QN-05</td>
<td>QN-02</td>
<td>0.6961</td>
</tr>
<tr>
<td>8</td>
<td>QN-01</td>
<td>QN-04</td>
<td>0.8399</td>
</tr>
<tr>
<td>9</td>
<td>QN-01</td>
<td>QN-03</td>
<td>0.8968</td>
</tr>
<tr>
<td>10</td>
<td>QN-04</td>
<td>QN-02</td>
<td>0.7541</td>
</tr>
</tbody>
</table>

Fig. 5  (a) The graph of total fracture measurements at 05 survey sites; (b) The graph of fracture measurements in the direction of NW-SE at 05 survey sites.

Fig. 6  The graph of the frequency of fracture number: (a) Within 20 degree for dip direction; (b) Within 10 degree for dip angle.

(b) quite coincides each other among survey sites. In Fig. 6a, the peaks of dip direction distribution frequency at 05 survey sites concentrate following to three different intervals of 40-90°, 130-190° and 210-270°. In Fig. 5b, frequency of dip angle at 05 survey sites is the curves, increasing from 30°, 50° and 60° to 90° at each different survey sites, reflects well the results of Fig. 4.

4. Discussions

The analytical results from the stereonet contour of fracture poles in Fig. 5 indicated that, the obtained
fracture orientations at 05 different survey sites develop following 02 main direction NW-SE and sub-horizontal, while there are over 60% fractures number in NW-SE direction, which nearly coincide with the Cao Bang-Tien Yen fault zone. The existence of the fracture sets may be in relation to different tectonic phases which occurred in the period of before and during the Cenozoic Era.

Beside the collecting and analyzing the fracture measurements, this study also considers the striate on the fault surface to interpret tectonic characteristics in the area. However, the main content of this paper only considers the fracture orientation distribution and the analytical results of striate data which will be supported for discussing on the existence of the difference among fracture sets.

The analytical results of striate measurements at 05 survey sites in Fig. 7 indicated that, there are 02 main tectonic activity phases which occured in this study area and the most direction-dominated is the NW-SE, similar to most fracture orientations at 05 different survey sites along the Cao Bang-Tien Yen fault zone.

5. Conclusions

The results of quantitative analysis of fracture distribution according to the pairs of stereonet windows among 05 different survey sites along the segment of Tien Yen to Mui Chua, belong to Cao Bang-Tien Yen fault zone indicated that, the correlation values are over 0.80 corresponding to 50%, over 0.75 corresponding to 30% and over 0.65 corresponding to 20%. These values are quite consistent with over 60% of the fracture number in the direction of NW-SE. Especially, their compatibility is also reflected in the determination of the fracture frequency within the division intervals 20 degrees for dip direction and 10 degrees for dip angle at 05 different survey sites. The high correlation coefficient of fracture distribution among different survey sites within fault zone showed clearly that they are affected.
Some Results of Quantitative Analysis of Fracture Orientation Distribution along the Segment Tien Yen-Mui Chua of Cao Bang-Tien Yen Fault Zone, Quang Ninh Province, Viet Nam

by the similar geodynamic conditions. The obtained results in this study continuously confirm the important significance of using this method in analyzing fracture domain from fracture orientation.

However, in order to ensure the conviction of method for analyzing fracture orientations in the fault zone, the study should be conducted at much more survey sites along different fault zones.

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References


