Delineate Structural Boundary from Fracture Correlation Coefficients

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Abstract

The similarity of fracture patterns inside rockmass among adjacent regions is characterized by high correlation coefficient of them on stereographic projection. This is confirmed from experimental results at four different survey sites in South Korea.

The calculation of fracture correlation coefficient are carried out on two stereonet windows of two successive segments by moving continuously stereonet window couples along the depth of each borehole. The correlation values obtained from each borehole can be used to delineate structural domain boundary and then these results are also compared with the nearby ones to determine the spatial distribution of fracture patterns inside rockmass. The experimental results from four pairs of boreholes with 1880 fracture measuments and total depth of 560m have confirmed the significance of this method in identifying structural boundary.

Keywords: Structural domain, Fracture correlation coefficient, Stereonet windows, RQD values, Fracture number.

1. Introduction

A structural domain shows a volume of rock mass, characterized by a distinct pattern distribution of fractures by the intensity, orientation, spacing, size and shape. However, only the number of fractures (intensity) and their orientation distributions are considered for determining structural domain boundary in this study. The identification of structural domain is very important for rock engineering investigation because of its close relationship to hydrologic properties and potential failure of rock blocks. The studies of structural domain have received a lot of attention from the past decades by the authors: Miller, 1983; Kulatilake et al., 1990; Michael et al., 2004. Miller (1983) used Chi Square method to compare Schmidt plots in pairs and evaluate the homogeneity of structural populations from a contingency table analysis based on the frequencies of fracture poles that occur in corresponding cells of the Schmidt plots. However, this method has limitation in terms of the number of fracture poles in each window and the expected frequency of fracture poles. Kulatilake et al. (1990) used the methods of Miller (1983) and Mahtab and Yegulalp (1984) combined with a visual comparison of stereonets to identify homogeneous regions. Michael et al. (2004) calculated correlation according to fracture frequency between two stereonet windows to quantify the degree of their similarities for determining structural boundary. The structural boundary is established wherever the fracture correlation coefficient between two stereonet windows is low. Recently, Nguyen et al. (2012) has also used correlation coefficient method to analyze fracture frequency along a tunnel for determining structural domain boundaries.

The above studies provided helpful tools for determining fracture patterns inside the rockmass and identifying structural domain boundaries. However, the most above analyses were conducted independently without comparing with the results of the adjacent areas. Therefore, the aim of this study is to extend the correlation method and present the comparison results from four different survey sites in South Korea.

2. Methodology

The methodology used in this study is to calculate correlation coefficient of fracture orientation frequency between two stereonet windows of two successive segments along borehole depth. The fracture orientation frequency is the number of fracture poles in each cell of stereonet that is plotted on the lower hemisphere projection (Fig. 1). The stereonet window is designed according to dip direction and dip angle of fracture orientation. Each stereonet window contains cells of the same sizes. The design of cell size on stereonet is very important because if the cell size is too large, it will be overly smooth data and if the cell size is too small, the trends will be rendered unrecognizable due to the scattered plotting of random poles. In this study, a lower hemispherical Schmidt net with equal-area plot is utilized for stereonet window (Fig. 1).

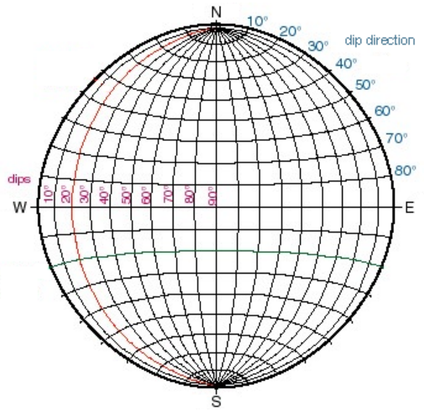

Figure 1. Lower hemispherical Schmidt net as stereonet window

After plotting fracture orientations of each segment in the cells of the window (Fig. 2), the calculation of fracture correlation coefficient between two successive stereonet windows is carried out by using Equation 1. During the calculating, length of each borehole segment chosen for stereonet window is arbitrary as long as the fracture correlation coefficient can be used for expressing distribution of structural domain. In this study, the length of each borehole segment is chosen as 2.5, 3.0, 3.5, 4.0 and 4.5m.

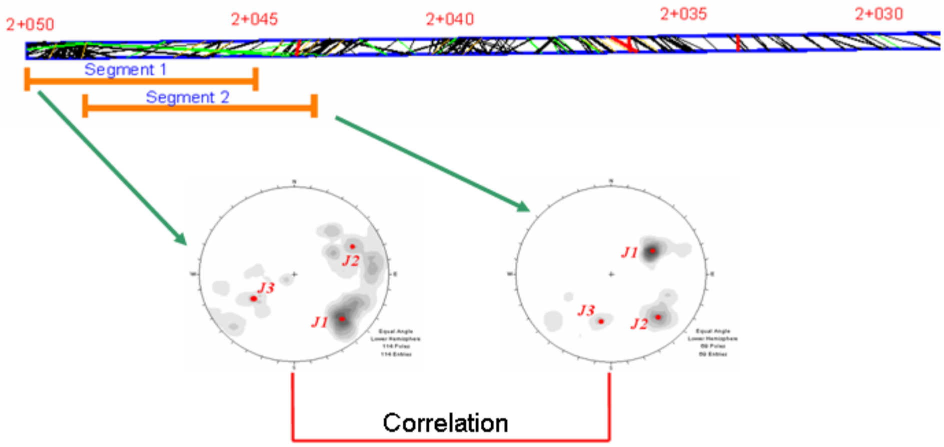

Figure 2. Stereonet pole plot of two successive segments

The fracture correlation coefficient between two successive stereonet windows is calculated as formula (1).

$$Correl(x,y)=\frac{\sum(x-\overline{X})(y-\overline{Y})}{\sqrt{\sum(x-\overline{X})^2}\sqrt{\sum(y-\overline{Y})^2}} \tag{1}$$

Where: x and y are number of fractures in each cell of two successive stereonet windows; $\overline{X}$ and $\overline{Y}$ are the average values of fracture number of two successive stereonet windows.

The fracture correlation coefficient between two successive stereonet windows is calculated following each pair of offset segments 0.5m and moved by interval 0.5m along borehole depth (Fig. 3). The Figure 3 shows the fracture orientation correlation versus borehole depth.

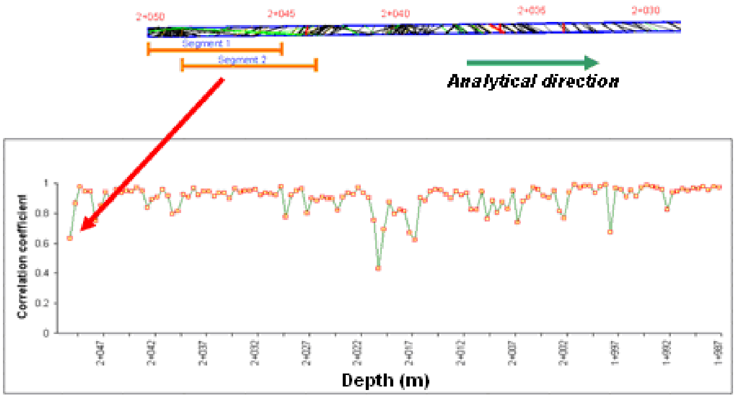

Figure 3. Correlation coefficient of fracture distributions between two stereonet windows of successive segments along borehole depth

The correlation coefficient expresses the strength of the association between the two variables from two successive 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. In this study, the lowest correlations of association between successive stereonet windows are considered as the boundary between two structural domains (Fig. 4).

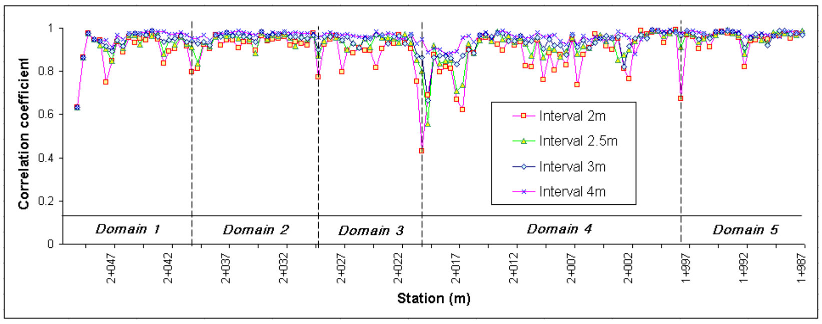

Figure 4. Domain divisions along BongHwang tunnel study section (Nguyen et al., 2009)

3. Application

The application of this study is conducted by calculating fracture correlation coefficient between two stereonet windows of two successive segments along the depth of four pair of boreholes from four different areas in the South Korea. The data used in this analysis is Borehole of Image Processing System (BIPS) data. The analytical process is separately carried out for four different areas as denoted in figure 5.

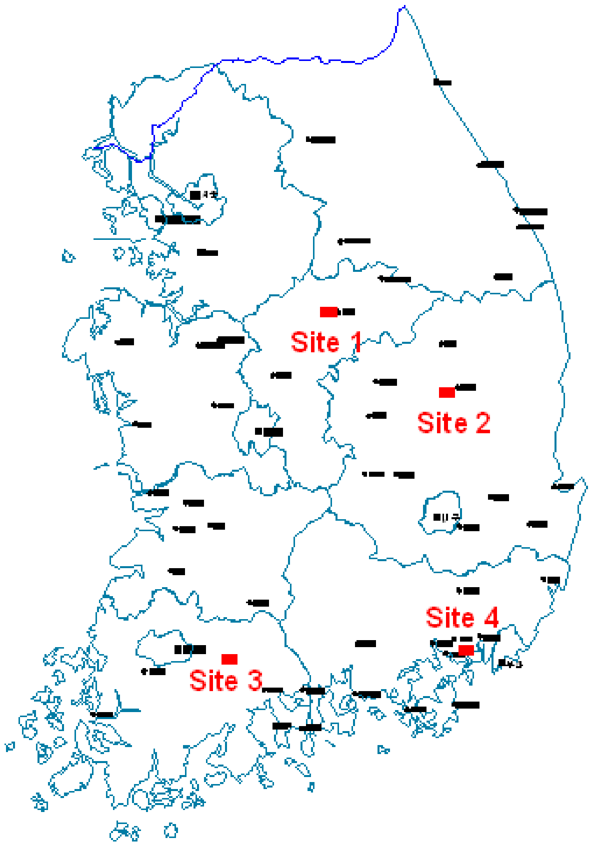

Figure 5. Location of four study areas in South Korea

3.1. Site 1

The site 1 is located near ChungJu city, Chungbuk province, South Korea (Fig. 5). Two boreholes BH-2 and BH-4 in this area are used to calculate fracture correlation coefficient. The distance between two boreholes is about 61m and the elevation of them is quite similar. Two boreholes are drilled in biotite granite rock with the depths of 22m and 21m. The number of measured fractures in two boreholes is 72 and 157, respectively. The RQD values them calculated according to Deer's formula are 93.26% and 81.13%. Although the distance between two boreholes is not too far, the distribution of fracture orientations between them is quite different (Fig. 6). The fracture correlation coefficient between two boreholes is only 0.4 (40%). The distribution of fracture contour poles of two boreholes is shown as in Figure 6.

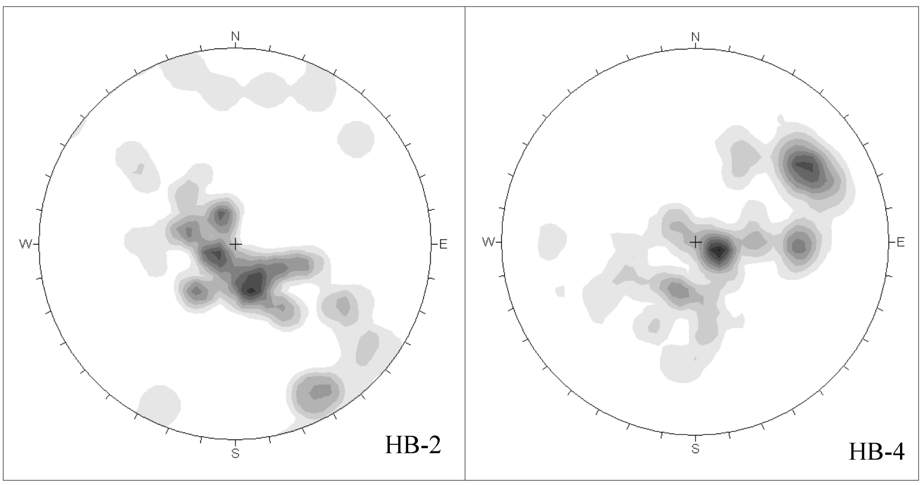

Figure 6. Contour poles of fracture orientations of two boreholes BH-2 and BH-4

The fracture correlation coefficient between two stereonet windows of two successive segments along the depth of two boreholes is calculated according to various segment lengths of 2.5, 3.0, 3.5 and 4.0 m and shown as in Figure 7.

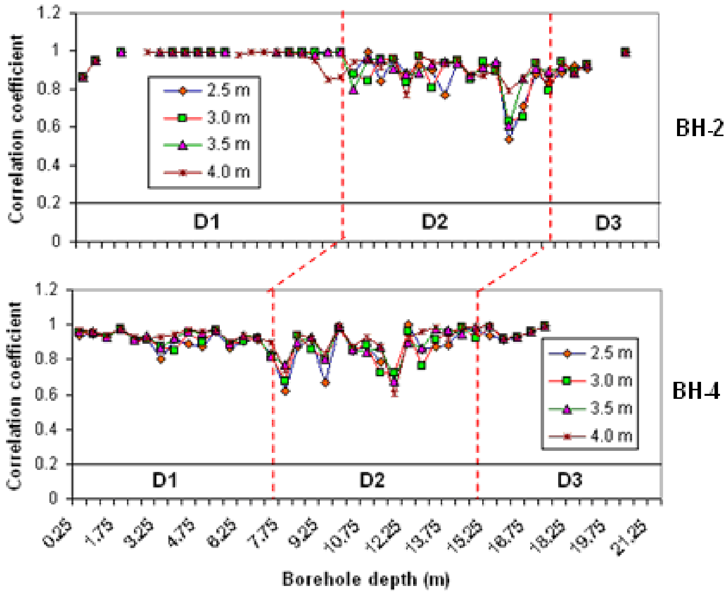

Figure 7. Illustration of fracture correlation coefficient of two boreholes BH-2 and BH-4

Base of geometric changes of fracture correlation values along boreholes BH-2 and BH-4 on Figure 7, the structural domains can be determined as D1, D2 and D3. These structural domains lie in different depths and are quite clear. The structural domains in the borehole BH-4 are more shallow than the structural domains in the borehole BH-2. The various depths of structural domains between two boreholes can be caused by tectonic subsidence activity in this area.

3.2. Site 2

The site 2 is located at near AnDong city, Gyongbuk province, South Korea (Fig. 5). Two boreholes TB-5 and TB-6 are used to calculate fracture correlation coefficient. The distance between two boreholes is about 115m and the deviation of surface elevation between two boreholes is about 20m (Fig. 9). These boreholes are drilled in the rock of biotite granite and granitic gneiss of Jurassic period with their depths are 84.22m and 80.47m. The number of measured fractures in two boreholes is 318 and 234, respectively. The RQD values of two boreholes calculated according to Deer's formula are 96.37% and 92.94%. The fracture correlation coefficient between two boreholes is 0.82 (82%). The distribution of fracture contour poles between two boreholes is quite similar and shown in Figure 8.

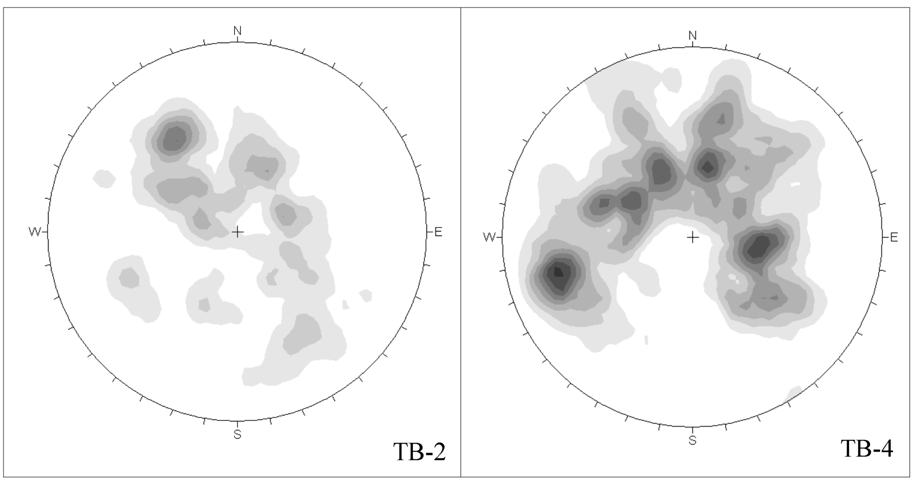

Figure 8. Contour poles of fracture orientations of two boreholes TB-5 and TB-6

The fracture correlation coefficient between two stereonet windows of two successive segments along the depth of two boreholes is calculated according to various segment lengths of 3.0, 3.5, 4.0 and 4.5m and shown in figure 9.

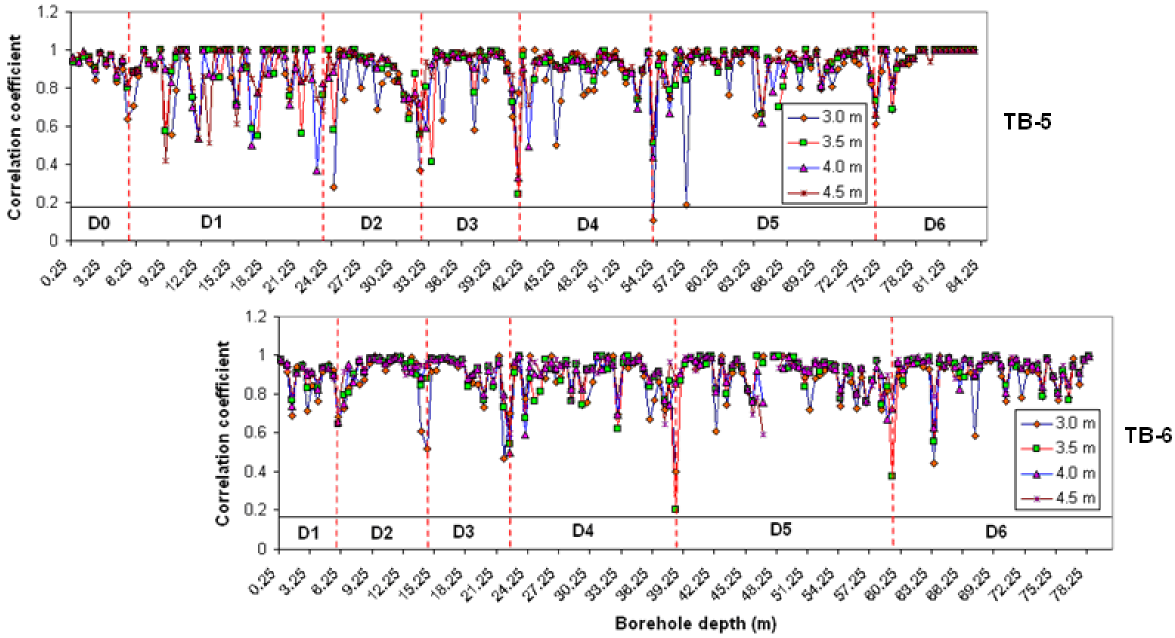

Figure 9. Illustration of fracture correlation coefficient of two boreholes TB-5 and TB-6

Base of geometric changes of fracture correlation values, along boreholes TB-5 can be determined seven structural domains corresponding to D0, D1, D2, D3, D4, D5 and D6 as in Figure 9 and along boreholes TB-6 can be determined six structural domains corresponding to D1, D2, D3, D4, D5 and D6 as in Figure 9. In the Figure 9, the structural domains D1, D2, D3, D4, D5 and D6 are quite match at the same depths in both borehole TB-5 and TB-6. However, the small difference on the surface between two boreholes may be due to erosion on the surface of Borehole TB-6.

3.3. Site 3

The site 3 is located at near Juam dam area, about 30km southeast of Gwangju city, South Korea (Fig. 5). Two boreholes BH-4 and BH-5 are used to calculate fracture correlation coefficient. The distance between two boreholes is about 61m. These boreholes are drilled in granitic gneiss (Pre-Cambrian) with their depths are 58.21m and 72.82m. The number of measured fractures in two boreholes is 157 and 155, respectively. The RQD values of two boreholes calculated according to Deer's formula are 97.89% and 97.31%. The RQD values of two boreholes show that the degree of broken rocks between them is quite similar. The fracture correlation coefficient between two boreholes is 0.85 (85%). The distribution of fracture contour poles of two boreholes is shown as in figure 10.

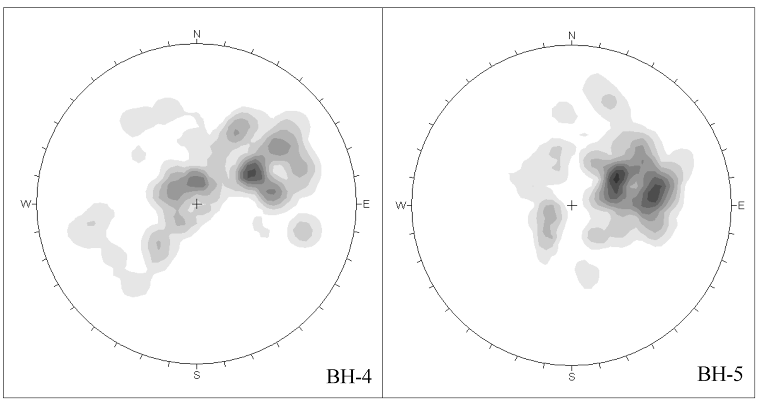

Figure 10. Contour poles of fracture orientations in two boreholes BH-4 and BH-5

The fracture correlation coefficient between two stereonet windows of two successive segments along the depth of two boreholes is calculated according to various segment lengths of 3.0, 3.5, 4.0 and 4.5m and shown in Figure 11.

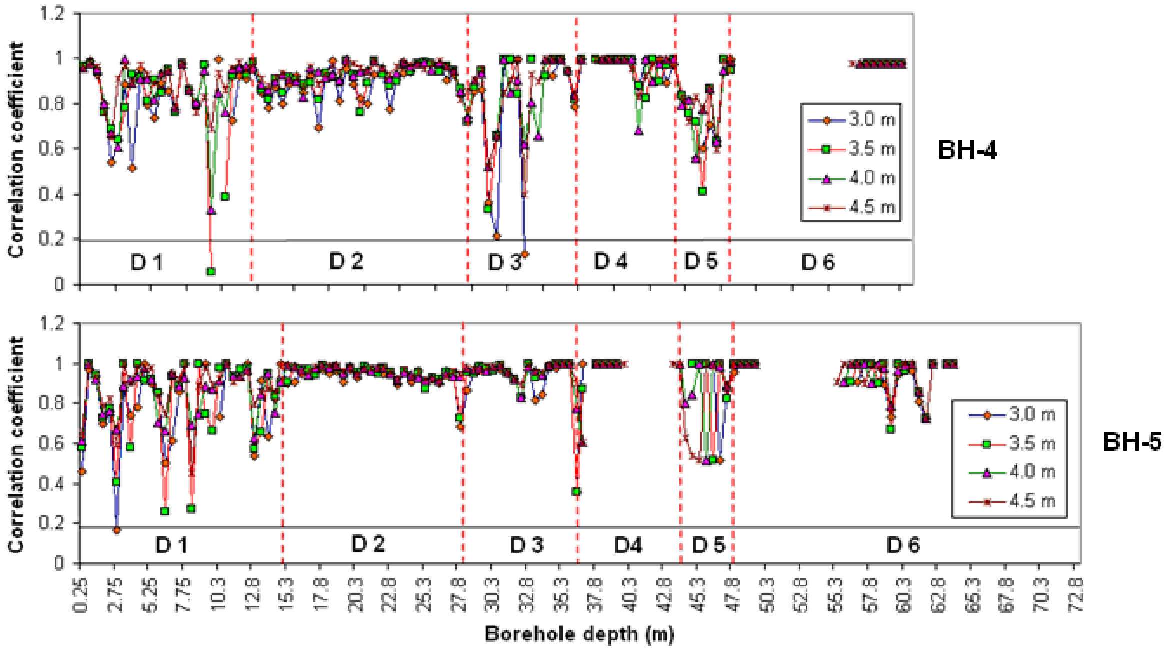

Figure 11. Illustration of fracture correlation coefficient of boreholes BH-4 and BH-5

Base of geometric changes of fracture correlation values along two boreholes BH-4 and BH-5 in the Figure 11, the structural domains can be determined as D1, D2, D3, D4, D5 and D6. These structural domains are quite match at the same depths in both boreholes.

3.4. Site 4

The Site 4 located at about distance 22km west of Busan city, South Korea (Fig. 5). Two boreholes ATB-27 and ATB-25 are used to calculate fracture correlation coefficient. The distance between two boreholes is about 399m. These boreholes are drilled in the rhyodacite rocks of Yucheon Group with their depths are 77.11m and 144.78m. The number of measured fractures in two boreholes is 505 and 282, respectively. The RQD values of two boreholes calculated according to Deer's formula are 92.68% and 91.28%. These values obtained from two boreholes show that the degree of broken rocks between them is quite similar. However, the fracture correlation coefficient between two boreholes is only 68%. The distribution of fracture contour poles of two boreholes ATB-27 and ATB-25 is show in figure 12.

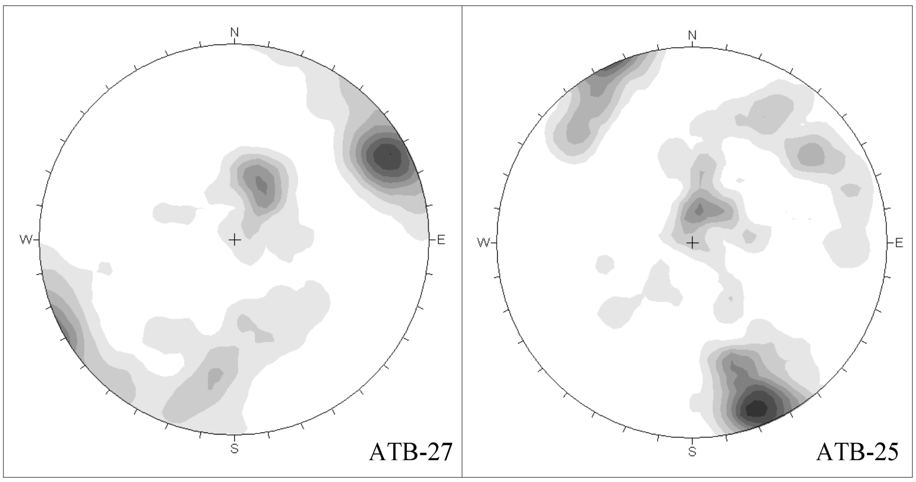

Figure 12. Contour poles of fracture orientations in two boreholes ATB-27 and ATB-25

The fracture correlation coefficient between two stereonet windows of two successive segments along the depth of two boreholes is calculated according to various segment lengths of 3.0, 3.5, 4.0, and 4.5m and shown in Figure 13.

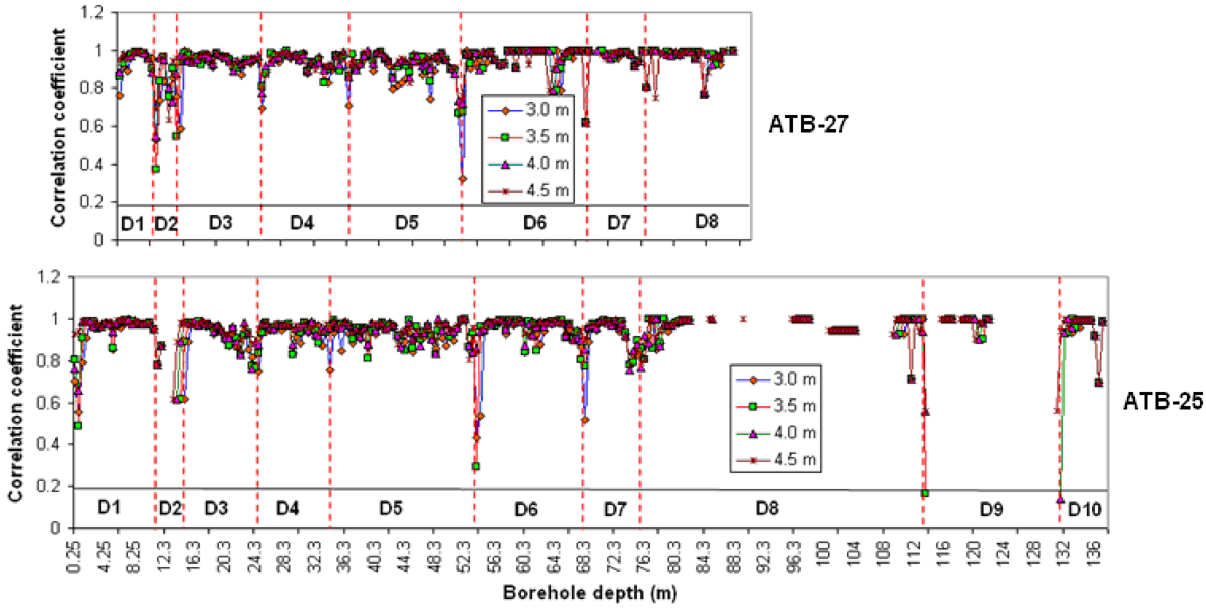

Figure 13. Illustration of fracture correlation coefficient of two boreholes ATB-27 and ATB-25

Base of geometric changes of fracture correlation coefficients, along borehole ATB-27 can be determined eight structural domains D1, D2, D3, D4, D5, D6, D7 and D8 and along borehole ATB-25 can delineate ten structural domains D1, D2, D3, D4, D5, D6, D7, D8, D9 and D10. The structural domains from D1 to D8 are quite match at the same depths in both boreholes.

4. Conclusions and discussions

The obtained experimental results by calculating fracture correlation coefficient between two stereonet windows of two successive offset segments 0.5m and segment lengths of 2.5, 3.0, 3.5, 4.0 and 4.5m and moving 0.5m along the depth of four pair of boreholes from four different sites in South Korea have clearly reflected the spatial fracture patterns inside the rockmass and their structural domains. The boundary among structural domains can be easily determined based on the the abrupt changes of fracture correlation coefficients at different depths. The comparison results of fracture correlation coefficient from four pair of boreholes at four different areas in South Korea have shown that the first one, the structural domain boundaries are quite matched at different depths; the last three ones, the structural domain boundaries are quite matched at the same depths. These experimental results have confirmed further using the fracture correlation coefficient method in determining structural domain boundary from previous studies. However, in order to have reasonable results, the experiment should be conducted at various values of segment lengths, successive offset segments and movement. These threshold values will be changed depending on structural geology and distribution of fracture orientations.

Acknowledgements: We would like to thank the support of the Project of Vietnam Academy of Science and Technology (VAST05.02/15-16) and GIS-Lab, PaiChai University, Korea to complete this paper.

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