STRUCTURAL DOMAIN IDENTIFICATION USING GEOGRAPHIC INFORMATION SYSTEM (GIS) BY FRACTURE ORIENTATION AND FRACTURE DENSISTY

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ABSTRACT

In every geohazard investigation, detailed study on the geological structures, geotechnical properties, drainage system and other related criteria will be carried out. For rock slope failures, geologic structure plays important role that controls the sliding and falling of rock blocks, hence structural domains should be identified to analyse the mode and the mechanism of failure model. A structural domain characterizes a volume of rock mass with similar rock properties, typically defined by the orientations of dominant joint sets, their strength characteristics and the rock type. When fracture orientations are considered only, the term fracture domain is applied.

Two approaches are developed to divide fracture pattern of rockmass into homogeneous domains: Stereonet correlation and fracture density analysis. The stereonet plots of fracture frequencies represented as poles at adjacent sections are used to calculate correlation coefficient to quantify the degree of similarity. Fracture domain boundaries were established wherever the correlation coefficient is low. The fracture density analysis is also performed along adjacent sections of reference line to track for the similarity of RQD values. The abrupt change in RQD values indicates the change of fracture domain boundary.

The analyses could reasonable establish the structural domain boundaries between regions on GIS platform by quantifying the degree of similarity between them. Knowledge of these structural domain boundaries allows a better understanding of geologic structure, failure modes and selection of suitable stabilization method to economical remedial slopes.

Keywords: structural domain identification, stereonet correlation, fracture density analysis, excavation stability.

1. INTRODUCTION

The characterization of the rock mass into the structural zones or regions could provide information about the similar geological conditions and hence similar physical properties and expected behaviour can be derived. A domain characterizes a volume of rock mass with similar rock properties, typically defined by the orientations of dominant joint sets, their strength characteristics and the rock type.

Rock mass stability is heavily based on fracture distributions, it is necessary to examine the spatial distribution of fractures to identify regions or structural domains that exhibited similar fracture sets. In most excavation site, geological contacts between different rock types could not be used to identify potential structural domains because the rock at the site was essentially the same. Therefore, it was necessary to examine the spatial distribution of fractures (especially their orientation). When fracture orientations are considered only, the term fracture domain is applied. A fracture domain refers to a rock volume in which rock units show similar fracture frequency characteristics.

Normally, domains are divided by analysing fracture orientations on stereonet and visually compared dominant joint sets of surrounding areas. Experienced geologists then usually subjectively determine whether a structural boundary should be placed by looking at differences between stereonets from adjacent regions. However, when fracture orientations appear dispersed and random, visual comparisons are not sufficient to determine whether the samples were obtained from the same structural domain (Miller, 1983; Martin, 2004). Two approaches, stereonet correlation and fracture density analysis, are developed to divide fracture pattern of rock mass into homogeneous domains in a quantitative way.

2. FRACTURE DOMAIN ANALYSIS

2.1 Stereonet correlation of fracture data

The method could be summarized as: Stereonet plots of fractures at adjacent sections are used to calculate correlation coefficient to quantify the degree of similarity. Fracture domain boundaries were established wherever the correlation coefficient is low.

Stereonet is divided into grids as shown in figure 1. Choosing appropriately sized windows within the stereonet can be difficult. Windows too large tend to overly smooth the data, thereby masking important trends. Windows too small certainly contain few data, and any trends are rendered unrecognizable due to the scattered plotting of random poles. Having smaller window sizes would result in many containing little to no discontinuity data.

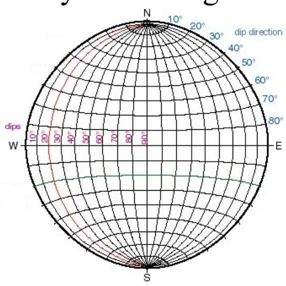


Figure 1. Lower hemispherical stereonet divided into small windows.

The current approach use 100 interval window on the stereonet for fracture pole plots. This facilitates statistical comparison of the number of poles lying in each window and the total number of window is 9 x 36 = 324. Figure 2 shows an example of number of fracture poles in spreadsheet type where dip angle and dip directions are put vertically and horizontally, respectively.

	10	20	30	40	50	60	70	80	90
10					1	1		1	
20			1		2	1	1		
30			1		3				
40	1			2	1				
50	1						2		
60			1		1	1	2	1	
70							3		
80		2	1	1	1	1	2		
90						1			
100		2	2			1			
110			3	2		1		1	
120		1	3		3	2		2	

	10	20	30	40	50	60	70	80	90
10				1	1			1	
20						1			
30									
40					1		1		
50				1		1	1	2	
60				2		1	2	2	
70		1			1	2	1	3	
80					2	1	6	8	
90				2	1	2	2	3	
100			1	4		2	2	2	
110				2	1	5	1	1	
120			2	4	2	4	1	2	

Figure 2. Fracture pole number on stereonet representing in spreadsheet type.

The scattering of data can cause biases in correlation calculation as too many windows containing no fracture are accounted. This problem can be eliminated by normalization algorithm of averaging data using 3x3 moving windows. Then the number of "no fracture" windows will be reduced.

The correlation coefficient gives the strength of the association between the two variables. The correlation coefficient can be calculated via equation 1.

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

If no correlation between 2 regions then it is justifiable to combine regions 1 and 2 into a single representative domain, otherwise, 2 domains are identified. The proposed method has advantages in that windows containing no discontinuities are easily accounted for and clustering of poles into joints sets is not required.

2.2 Fracture density analysis

Another approach to help partition the rock mass into structural domains is the use of fracture density or fracture spacing. This approach bases on the concept that different domains would have different fracture densities. The fracture density can be represented as RQD values. The RQD calculation originates from rock classification of borehole data, however, its concept can be adapted to analyse fracture spacing. The calculation of RQD is shown in equation 2.

$$RQD = \frac{\sum \text{Length of core pieces} > 10\,\text{cm length}}{\text{Total length of core run}} \text{ X } 100\% \quad (2)$$

This approach ignores fracture orientations and uses RQD values as the representative for fracture density along the tunnel line. The fracture frequency can be tracked for different intervals to identify potential boundaries between fracture domains. One problem with this approach is that two different populations of fracture orientations can give similar values for the spacing, and hence, the identified boundary does not capture the full distribution of orientations. The combination use of correlation method and this method would give better results of domain division.

These two methods could easily be performed on a GIS platform by following below procedures:

- Fracture data from a particular section can be projected to a reference line or whole section.
- Fracture orientation data for predefined segments will be plotted on a stereonet. The length of the segments will be defined by adjudging from the real data.
- Calculate a correlation coefficient of fracture occurrence in each window between two stereonets from two adjacent segments or regions.
- Repeat the process by running along the reference line or section, then plot the correlation coefficient versus location.

Low correlation coefficients indicate significant differences between stereonets and indicate the existence of fracture domain boundaries.

The fracture density analysis will also be performed to track for the similarity of RQD values. The abrupt change in RQD values indicates the change of fracture domain boundary.

3. APPLICATIONS

To test the applicability of these methods, 606 fractures over 62m tunnel length of Bong Hwang tunnel at Chungbuk province, Korea, have been used (fig. 3).

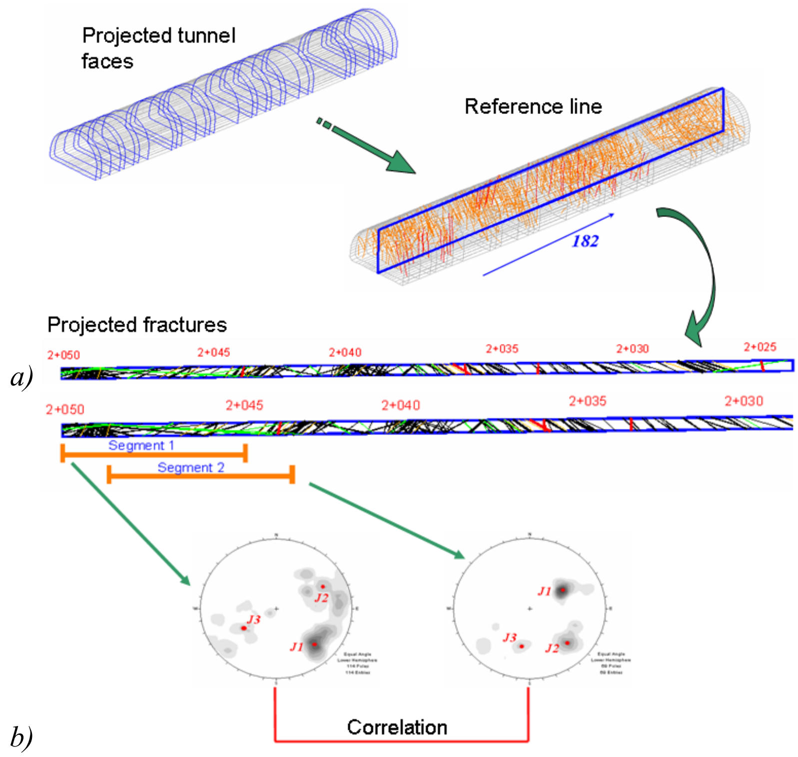


Figure 3. Stereonet correlation performance: *a)* Projected fractures on reference line, *b)* Stereonet plotting windows

In the correlation analysis, overlapping windows are compared and plotted as a graph of correlation coefficient versus tunnel position. The lowest correlations would occur when two slices lie at a structural boundary and the midpoint of the overlapping sections was taken to be division lines. Analysis along the tunnel has delineated 5 main structural boundaries (fig. 4).

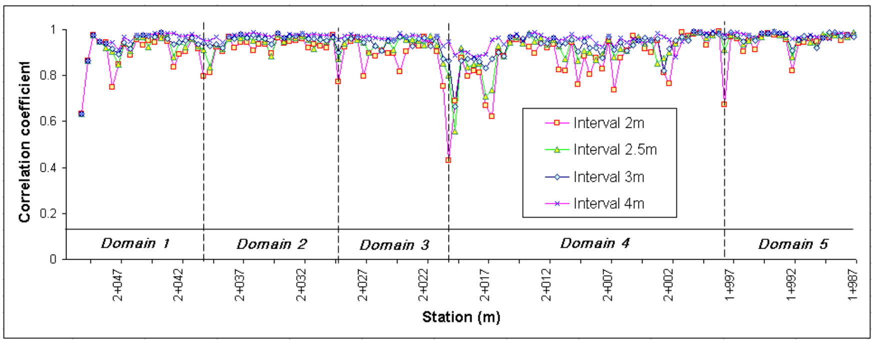


Figure 4. Correlation versus position along tunnel line.

The RQD analysis is also performed (fig.5), the change in correlation is significant enough to justify dividing the area into separate domains.

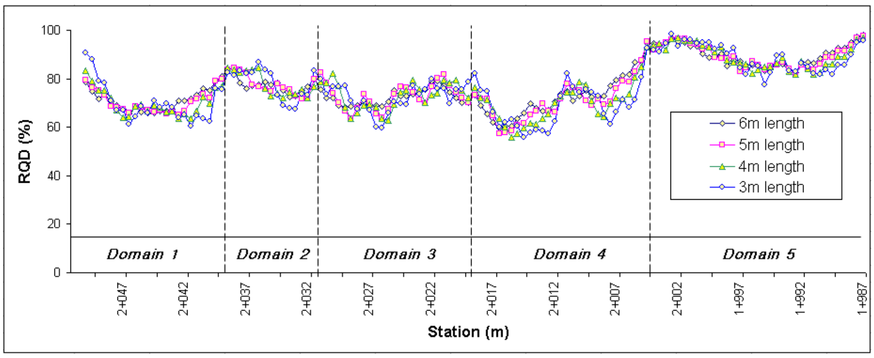
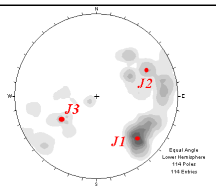
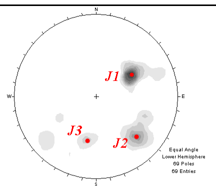
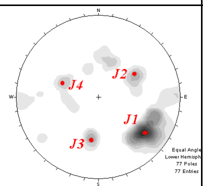
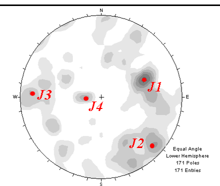
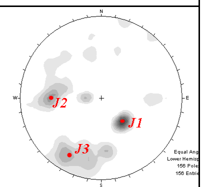


Figure 5. RQD versus position along tunnel line.

The RQD analysis do not clearly differentiates fracture domains as the fractures are evenly distributed along the tunnel line. However, by combination of the two analyses, it appears that the BongHwang tunnel area could be divided into five domains.

These domain divisions are then compared with the changes in rock types. The result shows that domain divisions agree very well with lithology boundary (table 1), especially at the change from limestone to shale. The domain boundaries were fortuitously chosen and the domain divisions somehow reflect the changes in lithology.

Table 1. Fracture domain division and stereonet of contoured poles.

Domains	**I**	**II**	**III**	**IV**	**V**
Lithology	Black slate and coal-bearing shale	Shale and coal-bearing shale	Shale and coal-bearing shale	Shale with small intercalations of limestone	Limestone
Fracture sets	J1: 316/70 J2: 244/69 J3: 054/52	J1: 238/52 J2: 313/68 J3: 012/56	J1: 308/69 J2: 238/53 J3: 010/54 J4: 110/49	J1: 248/58 J2: 314/80 J3: 092/80 J4: 090/22	J1: 318/41 J2: 090/63 J3: 028/77
Fracture distribution					

Fracture data collected from a constructing road near Jangheung district of Jeollanam province, Korea are also used to generate fracture domains on GIS platform. Domain boundaries are placed on top on fracture density map and the result is also indicated good distinction of fracture domains (fig.6).

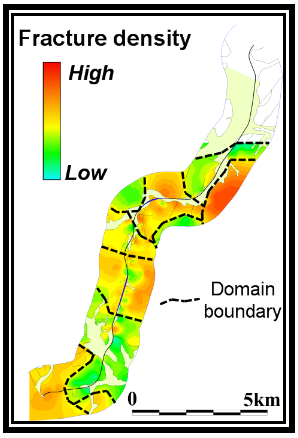


Figure 6. Domain boundaries are placed on top on fracture density map.

4. DISCUSSIONS AND CONCLUSION

The analysis results from a tunnel and a road section indicate that stereonet correlation and fracture density analysis are efficient tools in structural domain delineation. Knowledge of these structural domain boundaries allows a better understanding of the distribution of geologic structures. The correlation coefficient on stereonet and fracture density represented by RQD value from two adjacent segments give the idea of their similarity in term of fracture orientation and rock strength respectively. However, the fracture frequency approach ignores fracture orientation, so that, two different populations of fracture orientations can give similar values of fracture spacing, and hence, identified boundary does not capture the full distribution of orientations. The combination use of correlation method and fracture frequency method would give better results of domain division.

These methods are adaptive as they can be analysed spatially. Experiments on a tunnel and a road section show reasonable structural domain boundaries between regions by quantifying the degree of similarity between them. Further experience at other sites is needed to make guidance for defining significant correlation and RQD value for domain separation.

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