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DETERMINATION OF STATISTICAL HOMOGENEITY BY COMPREHENSIVELY CONSIDERING THE DISCONTINUITY INFORMATION

Yi-Guoa Xue, Shu-Caia Li, Dao-Honga Qiu, Zhe-Chaoa Wang, Mao-Xina Su

Original scientific paper
The statistical homogeneity of rock mass has always been an important issue in rock mass engineering. The rock mass of national underground oil storage in Huang Island is analyzed in this study with focus on the division of a statistically homogeneous area. Trace length is a basic element in determining crack features. The rock mass of different track lengths differs widely in terms of mechanics and deformation characteristics. This study includes trace length information in the division of a statistically homogeneous area and considers the variances and mean values of crack samples in different regions separately by F-test and T-test to determine if the samples have statistically similar trace length information. Numerous crack samples are required to divide a statistically homogeneous area. This study adopts the Watson test to divide a statistically homogeneous area and considers data on crack occurrence to achieve the purpose of obtaining fewer samples for occurrence comparison. Crack occurrence and trace length information are considered by integrating F-test, T-test, and Watson test to gather adequate basic information on cracks and obtain objective and reasonable results for statistical homogeneity.

Keywords: *discontinuous surface, hypothesis testing, rock mass, statistical homogeneity*

Određivanje statističke homogenosti detaljnom analizom podataka o diskontinuitetu

Izvorni znanstveni članak
Statistička homogenost stijenske mase oduvijek je važno pitanje u inženjerstvu stijenske mase. U ovom je radu analizirana stijenska masa podzemnog skladišta nafte na otoku Huang usmjerena na raspodjelu statistički homogenog područja. Duljina rasprostiranja je osnovni element za određivanje karakteristika pukotina. Stijenska masa različitih duljina rasprostiranja pukotina uvelike se razlikuje kad se radi o mehaničkim i karakteristikama deformacije. Ovaj rad obuhvaća podatke o duljini rasprostiranja u podjeli statistički homogenog područja i razmatra vrijednosti varijance i srednje vrijednosti uzoraka pukotina odvojeno u različitim područjima F-testom i T-testom kako bi se utvrdilo imaju li uzorci statistički slične podatke o duljini rasprostiranja. Potrebni su brojni uzorci pukotina da bi se dobilo statistički homogeno područje. U ovom je radu primijenjen Watsonov test za određivanje statistički homogenog područja i razmatrani su podaci o pojavi pukotina u svrhu dobivanja manjeg broja uzoraka za usporedbu pojave pukotina. Podaci o postojanju pukotina i duljini rasprostiranja analiziraju se uvođenjem F-testa, T-testa i Watson-testa kako bi se dobili osnovni podaci o pukotinama i objektivni i prihvatljivi rezultati za statističku homogenost.

Ključne riječi: *diskontinuirana površina, statistička homogenost, stijenska masa, testiranje hipoteze*

1 Introduction

Rock mass has a vast discontinuous surface and a constitutive network system. These two features allow rock mass to possess typical non-uniformity, anisotropy, and discontinuity [1, 2]. The distribution of rocks' discontinuous surface changes, manifesting as different properties of geology, geomechanics, and hydrogeology shift from one geological unit to another [3]. This shift makes the physical parameters of different units differ. Therefore, the discrepancy among different geological units must be considered in the analysis, modelling, and calculation of rock mass. Analysis of mechanics, deformation, and failure from a macro perspective can only be performed for statistically homogeneous units; thus, the determination of statistical homogeneity is the first step in building rock mass models and conducting deformation and stability analyses [4, 5].

Very few studies have focused on the statistical homogeneity of rock mass. Miller [6] was the first to consider the occurrences on the discontinuous surface of rocks. He projected discontinuous surface occurrences from different regions to the Schmidt equal-area net in the lower semisphere and adopted the association table method of stochastic mathematics to inspect the small squares in the projection net. This method determines the statistical homogeneity division of crack rock mass. Shanley and Mahtab [7] reported that discontinuous surface occurrence data could be represented by normal poles and 100 equal-area small squares in the episphere of a unit circle. The researchers also suggested the implementation of hypothesis testing to different partitions and dividing statistical homogeneity on this account. Kulatilake et al. [8] conducted studies and improvements on statistical homogeneity. Chen Jianping [9] improved the approaches proposed by Miller [6] and applied them to research on the permanent ship-lock chamber wall rock of The Three Gorges. This approach yielded favourable results. Kulatilake and Field [10] performed fractal calculations on crack with box dimension and divided statistical homogeneity. Lu Bo [11] conducted a study on rock mass representative volume element (RVE) and found that the upper limit of RVE is statistical homogeneity.

Previous researchers focused on discontinuous surface occurrences in the division of statistically homogeneous areas. However, the undulation shape, aperture, and trace length of a discontinuous surface can affect the nature of rock mass and influence the division of statistically homogeneous areas. For outcrop rock mass in the same area, the trace length of the discontinuous surface is a key factor that affects rock homogeneity, which is a significant consideration. Many discontinuous surface samples are required when the traditional method is utilized to divide statistical homogeneity. For example, the method proposed by Miller [6] requires discontinuous surface samples not less than 150. Satisfying this requirement is difficult in some outcrop and limited sampling areas. Dividing statistical homogeneity with only a few discontinuous surface samples is worth studying. This study adopts stochastic mathematical theories (T-test, F-Test, and Watson test) based on previous studies to overcome the defects of the above mentioned division method of statistical homogeneity. This study also considers the occurrences of discontinuous surfaces (inclination and dip) and trace length parameters to achieve objective and reasonable statistical homogeneity division results with only a few discontinuous surface samples.

2 Study area

2.1 General project situation

The current construction of an underground, water-sealed cavern in a hilly region bordered by Yellow Sea is the first large-scale underground crude oil warehouse construction project in China. The ridge elevation of this hilly landform ranges from 280 m to 350 m. The ridge is flanked to the north with klint and the 35° to 55°- steep slope is in the southern side. The southern and northern sides of the ridge form a deep gulch in the north-south and north-east directions. The main body of the cavern is located in the southern side of Long Que Mountain. The average ground elevation is 220 m. The highest point is at Dadingzhi, with an elevation of 350,9 m, whereas the lowest point is the pit mouth of the ZK012 drilling hole, with an elevation of 97,50 m. The comparative height difference is 253,40 m. The average annual precipitation in the project area ranges from 711,2 mm to 798,6 mm. Rainfall is concentrated in June to September.

The project area covers the lower reaches of the Changjiang River-Southern Yellow Sea and Tanlu earthquake zones, and belongs to Jiaonan-Weihai orogenic belt, which is the integrated belt of the North China-Yangtze Plate. The regional geological survey shows that shear zone and brittle fault structure are developed mainly in the orogenic belt, and folding tectonics is not developed. The project area is located at the southern margin of the Mouping-Jimo fault zone, which is the northeast-trending development zone and near the east west-trending fault. The direction of the faults near the storage area are as follows: the northeast-trending Laojuntashan fault is in the west, the northeast-trending Sunjiagou fault is in the east, and the east-west-trending Qianmaliangou fault is in the north. The above faults affected the selection of the storage location. Moreover, secondary faults and joints in the storage area have larger impact on the construction of the storage cavern. Based on the results of the survey on regional fault and structural plane, faults in the storage area mainly consist of Faults F1, F2, F3, F4, and F7, as well as Fault Fracture Zones F8 and F9. The structural plane is divided into five regions: Region I is at NW 345°; Region II is the transition zone, with many structural surfaces in the south-north direction and arising NE 45° structural surface in the dominant direction; Region III is approximately at the south-north direction and NE 45° structural surface; Region IV is NE 45° to 60°, NE30°, and near the south-north structural surface; Region V is mainly NW 330° to 345°. The linear density of the structural surface (NF) in the storage address area is 0,0015 line/m. More than half the surrounding rock is Grade II. In the storage address area, the maximum ground stress in the axial direction is 10 MPa. The ground stress in the vertical axis direction over the horizontal plane is 6 MPa. The ground stress vertical to horizontal plane is 4 MPa. The uniaxial compressive strength is 100 MPa to 160 MPa. After the field experiment and indoor test, the penetration coefficient of the surrounding rock in the storage cavern is $K = 1\times10^{-4}$ m/d. The basic earthquake intensity (I) is Level 6.

The formation lithology in the storage address area can be divided into four main categories.

1) The Quaternary residual slope and diluvial layer are mostly brown-yellow-to-maroon sandy cohesive soil or breakstone containing cohesive soil, with a thickness of 0,55 m to 5 m.

2) The Early Cretaceous Monzogranite with light-coloured flesh-pink-to-ash-grey colour contains the following major minerals: plagioclase, potassium feldspar, quartz, and hornblende biotite. This Monzogranite belongs to the hard rock because of its fine-grained granitic texture, blocky structure, complete rock mass, and high strength.

3) The Late Proterozoic granite gneiss with light-coloured flesh-pink-to-light-steel-grey colour contains the following major minerals: potassium feldspar, plagioclase, quartz, and hornblende biotite, and belongs to the hard rock because of its fine-grained granitic gneiss texture, blocky structure, and its rock mass ranging from broken to complete, which accounts for more than 80 % of the rock mass in the storage cavern.

4) The Early Cretaceous lamprophyre and diorite with eyish-green-to-charcoal-grey colour, whose texture ranges from fine-grained to aphanic, and whose blocky structure has less strength than granitic gneiss, is easy to disintegrate because of its poor resistance to weathering.

The room compound of the oil storage cavern spreads in a north-western direction, with an east-west width of 600 m and south-north length of 838 m. The project consists of two parts: underground works and ground auxiliary facilities. The design capacity is 300×104 m^3. The designed service life of the cavern is 50 years. The underground oil storage cavern consists of 9 caverns. The cavern spans 20 m. The height of the cavern is 30 m. The cross-sectional shape is a straight wall with a round arch. The space between the cavern wall and the wall of the adjacent construction tunnel is designed to 25 m. The interval between the two caverns is 30 m.

2.2 Window fracture analysis method

Most cracked surfaces are undulant and rough, straight and rough, or have small sweeping surface cracks. Rock debris without filled-in cracks or with very thin filling has good cementing properties.

Cracks of outcrop rock mass beside an oil storage tank were collected in this study through the window technique. Collection size is 80 m (length) × 2 m (height). A total of 251 random cracks were measured at the site. The starting point coordinate, end point coordinate, inclination, dip, and other parameters of every crack were recorded. The 251 cracks can be indicated by two-dimensional trajectories as illustrated in Fig. 1.

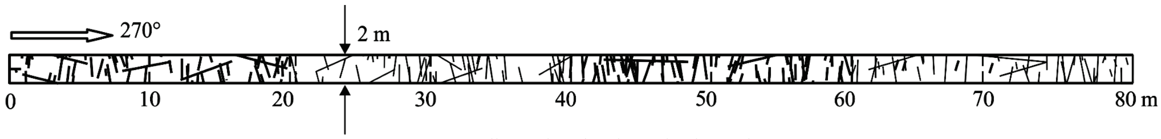

Figure 1 Two-dimensional trajectories in study area

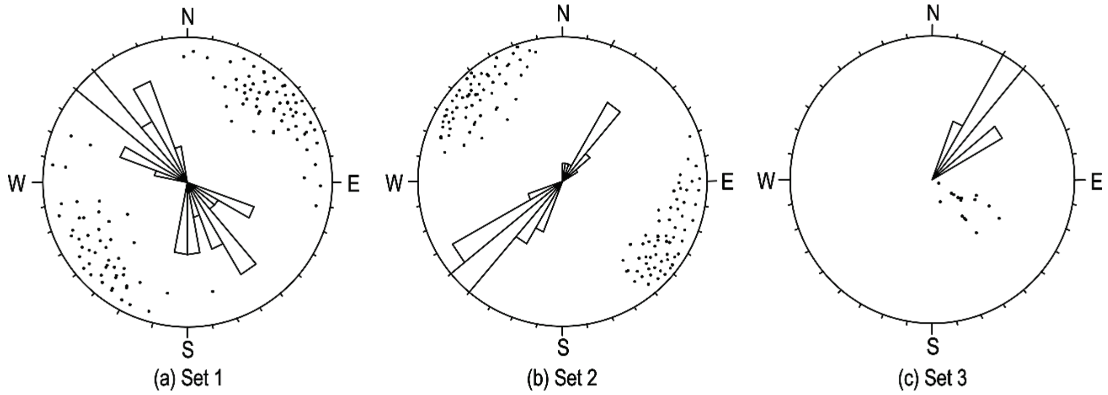

Figure 2 Rose and pole diagrams of the site development joint (based on right-handed rule)

The cracks were divided into three groups based on the advantage grouping method proposed by Chen et al. [2]. The crack number of each group is 112, 123, and 16, and the average occurrences in each group are 236°<77°, 311°<71°, and 128°<26°. Rose and pole diagrams were created for each advantage group through right-handed rule. The results are shown in Fig. 2.

3 Analytical method

The mechanics, deformation, and failure characteristics of rock mass are mainly determined by cracks. Occurrences (inclination and dip) and trace length are the fundamental factors affecting crack features. Other factors such as aperture, filler, and undulant shape also have effects on crack features; however, their effects on the properties of overall rock mass are much weaker than the effects of occurrences and trace length. Therefore, analysing statistical homogeneity through occurrences and trace length can adequately reflect crack features and the nature of overall rock mass. Through trace length and crack occurrence information, a decision method can be adopted to determine whether the area between two target areas is statistically homogenous. For example, two rock mass outcrop areas (A and B) are analysed; the two areas are of the same size. The trace lengths of cracks in the two areas are counted. If the trace lengths of these two areas have the same mean values and variances, then their trace length information is similar. Crack occurrences are constituted by inclination and dip, which cannot be separated. Therefore, inclination and dip should be considered together during analysis. The traditional method projects occurrence information to the spherical body through Schmidt projection and reflects inclination and dip information comprehensively. If the cracks in areas A and B have the same mean direction and concentration, then the areas have the same occurrence information. Areas A and B are statistically homogenous areas when they have similar statistical trace length and occurrence characteristics.

The T- and F-statistical tests were performed to determine whether the zones A and B possess the same trace length information. The T-test (Student test) assesses whether the means of two groups are statistically different from each other. The T-test was used to investigate the null hypothesis that data in both groups (i.e. sample sizes) were independent random samples from normal distributions with equal means and unknown variances. This was tested against the alternative hypothesis that the means were not equal. The F-test was used to determine whether the variances of the collected trace lengths for different sample sizes, were statistically the same. An F-test was performed to validate the null hypothesis that two independent samples were from normal distributions with the same variance, against the alternative that they were from normal distributions with different variances [12]. T and F statistical tests test more common use, this article will not repeat.

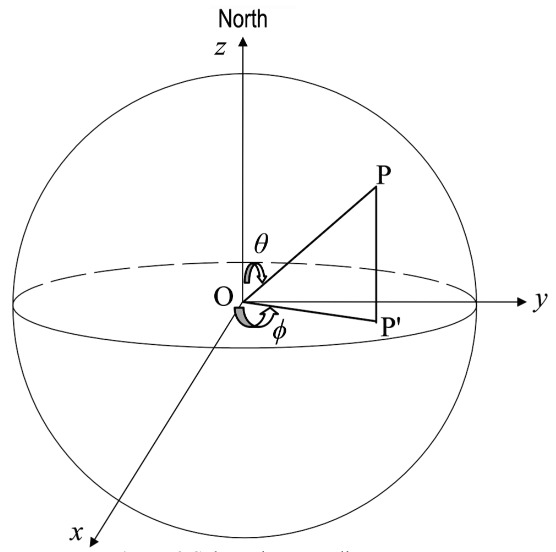

Figure 3 Sphere data coordinate system

The occurrences of cracks can be regarded as spherical data, indicating that cracks can be projected to a sphere based on inclination and dip angle. A spherical coordinate system was established in this study as illustrated in Fig. 3. A point on the spherical surface represents the occurrence of a crack, which can be indicated by θ or ϕ. ϕ denotes the angle between the x axis and OP' (P' is the projection of spherical point P in xOy surface, and OP' is the ligature between P' and the sphere center) when the x axis rotates counter clockwise. θ denotes the angle between the z axis and OP when the z axis rotates clockwise. The relationship between ϕ and inclination D of crack occurrences and dip A is shown in Eq. (1).

$$\begin{cases} \theta = D + 90° \\ \phi = 360° - A \end{cases} . \tag{1}$$

The orthogonal coordinates of one point on the spherical surface are

$$\begin{cases} x = \cos\theta\cos\phi \\ y = \cos\theta\sin\phi \\ z = -\sin\theta \end{cases} . \tag{2}$$

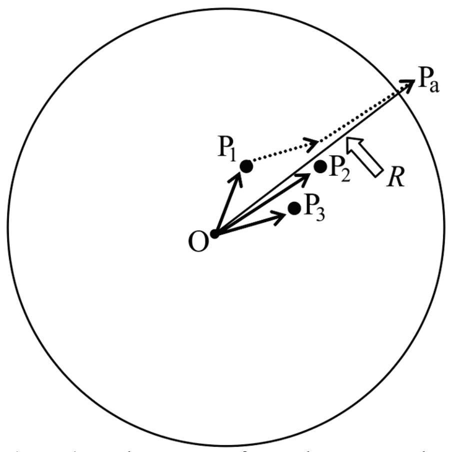

Figure 4 Resultant vector of several occurrence data

In this study, n cracks are considered and mean direction and concentration represent overall occurrence information. Circle centre O in Fig. 4 is connected to every point of crack occurrence, forming a direction vector. Head-tail technique was applied to every direction vector, which is denoted by OP_a. The direction of OP_a can be regarded as the mean direction of n cracks ($n = 3$ in this case); the relationship of R, the length of OP_a, to n can serve as the concentration parameter of n cracks. θ_κ and ϕ_κ, sphere data of R and mean direction, can be resolved by Eq. (3).

$$\begin{cases} S_x = \sum_{i=1}^{n} x_i, \quad S_y = \sum_{i=1}^{n} y_i, \quad S_z = \sum_{i=1}^{n} z_i \\ R = \sqrt{(S_x)^2 + (S_y)^2 + (S_z)^2} \\ x_\kappa = S_x / R, \quad y_\kappa = S_y / R \quad z_\kappa = S_z / R \\ \theta_\kappa = \arccos(z_\kappa), \quad \phi_\kappa = \arctan(x_\kappa / y_\kappa) \end{cases} . \tag{3}$$

If the discontinuous surface in areas A and B has similar statistical mean direction and concentration parameters, then the occurrence information of these two areas is also similar. Watson-test was adopted to compare the occurrence information of these two samples [13]. Watson test can inspect and verify if the mean direction and concentration parameters of these two crack sample groups are statistically similar. The test statistic values are shown in Eqs. (4) and (5), respectively.

$$Z = (R_1 + R_2) / (n_1 + n_2), \tag{4}$$

$$Z' = \begin{cases} Z_0 & \text{if} \quad Z_0 \geq 1 \\ 1/Z_0 & \text{if} \quad Z_0 < 1 \end{cases}, \tag{5}$$

where R_1 and R_2 are the resultant lengths of fracture traces in zones A and B, respectively; n_1 and n_2 are the fracture number in zones A and B, respectively; Z_0 can be determined by Eq. (6)

$$Z_0 = (n_2 - 1)(n_1 - R_1) / [(n_1 - 1)(n_2 - R_2)]. \tag{6}$$

The test statistic values should be compared with the critical values. If the test statistic is smaller than the critical value, the fracture occurrence data for the two zones are statistically the same. The critical values Z for checking the mean direction can be determined as following: if $n_1 = n_2$ and $\overline{R} \leq 0{,}75$ (Eq. (7)), the critical value corresponding to $\overline{R}$ and significance level α can be determined in Appendix A20 in Fisher et al. [13]. If $n_1 = n_2$ and $\overline{R} > 0{,}75$, find the upper 100α % point in the $F_{2,\, 2(n1+n2)-4}$ distribution from Appendix A5 in Fisher and Embleton as f', and take z_0 in Eq. (7) as the critical value. If $n_1 \neq n_2$, the critical value can be determined by interpolation using the data in Appendix A20 and A21 in Fisher et al. [13].

$$\begin{cases} \overline{R} = [(\sum_{i=1}^{2} R_i x_{\kappa i}) + (\sum_{i=1}^{2} R_i y_{\kappa i}) + (\sum_{i=1}^{2} R_i z_{\kappa i})]^{1/2} / (n_1 + n_2) \\ z_0 = [\overline{R} + f' / (n_1 + n_2 - 2)] / [1 + f' / (n_1 + n_2 - 2)] \end{cases} . \tag{7}$$

$\overline{R}_1$ and $\overline{R}_2$ should be larger than 0,65 before applying the critical values Z' for checking the mean direction. Use the upper $100(\alpha/2)$ percentile of the $F_{2n1-2,\, 2n2-2}$ distribution from Appendix A5 in Fisher et al. [13].

The following were noted when statistical homogeneity was divided in this study.

1) Scan line or window method is preferable in actual trace length data collection process. For example, invisible trace lengths on one end or both ends often exist in a limited window range. Therefore, trace length information collected through window method is incomplete. Statistical homogeneity can be divided through the abovementioned stochastic mathematical methods; only visible trace length information within the window range is collected. Current methods cannot correct every crack trace length and can only obtain mean trace length within an area. The ratio of trace length in different types (both ends are invisible, one end is visible, and both ends visible) can affect overall trace length information. If the trace length statistics determined through stochastic mathematical methods in two areas are similar, the ratio of trace length of the abovementioned three types must be determined. If the ratio is consistent, then these two areas have statistically similar trace length information.

2) Watson test is often implemented in a group of discontinuous surfaces for advantage grouping. Therefore, advantage grouping of every crack is performed in advance during the inspection of occurrence information.

This study adopts different approaches to divide statistical homogeneity. Statistical homogeneity can be divided in four main steps: (1) inspecting the mean values of trace length by T-test; (2) inspecting the variances of trace length by F-test; (3) inspecting the mean direction of occurrences by Watson test; and (4) inspecting the concentration parameter of occurrences by Watson-test. The results of the different inspections may be inconsistent [14]. For example, the cracks in two areas may have similar mean directions but different concentration parameters. These two areas can be regarded as statistically homogenous only when the statistical results of the above four steps are similar.

4 Division of a statistically homogeneous area

Crack groups involve geological agents of different periods and different mechanical properties. The cracks in different groups often have different trace lengths and occurrences; therefore, dividing statistical homogeneity according to different groups is reasonable. Watson-test requires concentrative crack occurrences with Fisher distribution. The division of a statistically homogeneous area requires addressing various advantage groups separately. However, the crack number in a single unit obtained after actual grouping is too small to support statistical probability methods in the division of a statistically homogeneous area. This study adopts the following methods to resolve this problem. All cracks within the analyzed area are utilized to compare trace length instead of groups. The crack trace length of each group is reflected in the mean values and variances of overall trace length. Group comparison is conducted for occurrence information. The effect of advantage groups with few cracks on overall occurrences is ignored and is only considered to analyze advantage groups in large quantities.

Based on the cracks, the crack numbers of Groups 1 and 2 are larger than those of Group 3. Thus, the cracks of Group 1 are compared with those of Group 2 only in the comparison of occurrence information; the crack occurrences of Group 3 are ignored.

T-test and F-test require no specific crack numbers; however, Watson-test requires crack number to be more than 25 for every contrastive area. Therefore, the size of the contrastive area should be 20 m to ensure that the crack numbers of Groups 1 and 2 are more than 25.

The traditional method utilized to divide statistically homogeneous areas involves the comparison of adjacent areas. If the statistics of two areas are similar, then the adjacent areas are merged as one statistically homogenous area. The rocks in different sectors often represent statistical similarities. Discontinuous rock mass area is also significant in the division of statistically homogeneous areas. If two areas are statistically homogenous, then the mechanics and deformation characteristics of one area can be considered as a reference for the other area. Hence, this study determines the statistical homogeneity of two outcrop areas within a section of rock mass.

The results of the T-test and F-test for trace length are summarized in Tab. 1. All calculations were based on a maximum significance level of 5 %. The maximum significance level at which the null hypothesis cannot be rejected is the P-value. A high P-value indicates high probability that the mean values and variances of different sample sizes are equal. The test results of samples from each region are shown in Tab. 1. When the variances of trace length are considered separately, (0 m, 20 m) and (40 m, 60 m), (0 m, 20 m) and (60 m, 80 m), and (20 m, 40 m) and (60 m, 80 m) are statistically homogenous. When the mean values of trace length are considered separately, (0 m, 20 m) and (40 m, 60 m) and (20 m, 40 m) and (60 m, 80 m) are statistically homogenous. If the information of trace length is considered comprehensively, then only when the mean values and variances of trace length are similar in statistics can the two areas be statistically homogenous in terms of trace length.

Table 1 Tests of mean value and variance for trace lengths appling T-test and F-test

Sample	Sample bounds	Mean value of trace length (T-test)			Variance of trace length (F-test)		
		Critical P-Value	P-Value	Result	Critical P-Value	P-Value	Result
Zone A	(0, 20)	0,05	0,01	Rejected	0,05	0,002	Rejected
Zone B	(20, 40)						
Zone A	(0, 20)	0,05	0,052	Accepted	0,05	0,07	Accepted
Zone B	(40, 60)						
Zone A	(0, 20)	0,05	0,023	Rejected	0,05	0,54	Accepted
Zone B	(60, 80)						
Zone A	(20, 40)	0,05	0,045	Rejected	0,05	0,14	Rejected
Zone B	(40, 60)						
Zone A	(20, 40)	0,05	0,13	Accepted	0,05	0,21	Accepted
Zone B	(60, 80)						
Zone A	(40, 60)	0,05	0,089	Rejected	0,05	0,34	Rejected
Zone B	(60, 80)						

As mentioned in Chapter 3, the calculated and critical values of crack occurrences within two areas were compared through Watson-test; α was set to 0,05. When the calculated value is less than the critical value, the mean direction or concentration direction of crack samples can be considered statistically similar. $\overline{R}_1$ and $\overline{R}_2$ of each area obtained through calculation are all larger than 0,65; therefore, the critical value of concentration parameter can be calculated by Eq. (7). Similar to the trace length test for cracks, when mean direction and concentration parameter are considered separately, the statistically homogenous area is different. Only the area with similar mean direction and concentration parameter can be regarded as statistically homogeneous. Likewise, the areas in Groups 1 and 2 cannot be considered statistically homogenous unless the cracks of the two groups meet the requirements of homogeneity. When crack occurrences are considered comprehensively, (0 m, 20 m) and (40 m, 60 m) and (20 m, 40 m) and (60 m, 80 m) are statistically homogenous.

We consider the trace lengths and occurrences of any two contrastive areas comprehensively based on the discussion above. The areas can only be considered statistically homogeneous when trace length and occurrences are statistically similar. Therefore, the final conclusion for this engineering rock mass is that (0 m, 20 m) and (40 m, 60 m) and (20 m, 40 m) and (60 m, 80 m) are statistically homogenous.

Table 2 Tests of mean direction and concentration parameter for occurrences applying Watson test

Sample	Sample bounds	Mean direction						Concentration parameter				
		Set 1			Set 2			Set 1			Set 2	
		CRV	CAV	Result	CRV	CAV	Result	CRV	CAV	Result	CRV	CAV
Zone A	(0, 20)	643	701	Rejected	563	722	Rejected	2,018	2,567	Rejected	2,932	Rejected
Zone B	(20, 40)											
Zone A	(0, 20)	601	521	Accepted	612	492	Accepted	1,968	1,543	Accepted	1,892	Accepted
Zone B	(40, 60)											
Zone A	(0, 20)	503	576	Rejected	523	492	Accepted	2,002	1,984	Accepted	2,123	Rejected
Zone B	(60, 80)											
Zone A	(20, 40)	543	502	Accepted	689	602	Accepted	2,102	2,345	Rejected	2,432	Rejected
Zone B	(40, 60)											
Zone A	(20, 40)	592	561	Accepted	561	512	Accepted	1,992	1,687	Accepted	1,875	Accepted
Zone B	(60, 80)											
Zone A	(40, 60)	554	597	Rejected	572	750	Rejected	2,034	2,123	Rejected	2,342	Rejected
Zone B	(60, 80)											

CRV: critical value, CAV: Calculated value

The above results prove that the crack number applied in this study is small depending on the concentration of single-group and group-number advantages. If only one group dominates in terms of crack number, then 25 crack samples must be obtained from every area for the division of statistical homogeneity; the precision of Watson test depends on concentration parameter $\overline{R}$. If cracks are not concentrated, then they should be divided into groups to enlarge the crack number required for comparison.

5 Conclusion

Rock mass heterogeneity is mainly caused by the random outcropping discontinuous surface. Previous studies focused on crack occurrences and rarely considered trace length. This study considered the occurrences and trace lengths of discontinuous surfaces. Occurrences and trace lengths affect rock mass heterogeneity. Statistical homogeneity was divided through F-test, T-test, and Watson-test. T-test and F-test can verify if crack samples have statistically similar mean values and variances in trace length; Watson test can verify if crack samples have statistically similar mean direction and concentration of occurrences.

Crack features are determined by many factors. The major factors are mean values and variances in trace length as well as mean direction and concentration of occurrences. For the analysed areas, the consideration of different influencing factors provided different statistical results. For example, the statistics of the analysed areas may be similar in terms of one or several factors; however, other factors may differ significantly. Discontinuity information was considered comprehensively in the division of statistically homogenous areas. The analysed areas were considered statistically homogenous only when the different influencing factors were statistically similar.

The crack number applicable to the division of the statistically homogeneous area mainly depends on Watson-test. Specifically, crack number depends on the crack concentration of single group and crack groups of advantage. If only one group dominates in terms of crack number, then 25 crack samples must be collected from every area for the division of statistically homogeneous areas; the precision of Watson test depends on concentration parameter $\overline{R}$. If cracks are not concentrated, then they must be divided into groups to enlarge the crack number required for comparison.

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Authors' addresses

Yi-Guoa Xue
Corresponding author
Geotechnical & Structural Engineering Research Center of Shandong University
250012 Jinan, China
E-mail: xieagle@sdu.edu.cn

Shu-Caia Li
Geotechnical & Structural Engineering Research Center of Shandong University
250012 Jinan, China

Dao-Honga Qiu
Geotechnical & Structural Engineering Research Center of Shandong University
250012 Jinan, China

Zhe-Chaoa Wang
Geotechnical & Structural Engineering Research Center of Shandong University
250012 Jinan, China

Mao-Xina Su
Geotechnical & Structural Engineering Research Center of Shandong University
250012 Jinan, China

Location

Complex Systems 2015 will be held in the New Forest, which borders the south coast of England and is home to the Wessex Institute. The New Forest is situated in central southern England, 120km from London. Spreading over nearly 400 square kilometres, this National Park is home to picturesque villages, unspoiled scenery, abundant wildlife and many attractions for visitors. The New Forest was established as a royal hunting ground by the Norman King William I, and 900 years later, the New Forest is still owned by the Crown. Local commoners have the right to graze their ponies, cattle and pigs on forest land where they wander freely. The Forest is unarguably recognised as one of the most unique wilderness areas in Western Europe, where many landscapes have remained virtually unchanged for many centuries.

Conference Venue

Situated at the heart of the New Forest National Park, the Balmer Lawn Hotel has uniquely designed and decorated rooms. This 4 star hotel has its own restaurant, 3 acres of grounds, squash courts, tennis court, pools, sauna, spa and fitness suite as well as direct access to the New Forest. Only a short walk from the shops, pubs and restaurants of Brockenhust village and Brockenhurst train station, the hotel is easily accessible.

Submission Information

Papers are invited on the topics outlined and others falling within the scope of the meeting. Abstracts of no more than 300 words should be submitted as soon as possible.

Abstracts should clearly state the purpose, results and conclusions of the work to be described in the final paper. Final acceptance will be based on the full-length paper, which if accepted for publication must be presented at the conference.

The language of the conference will be English.

Online submission:
wessex.ac.uk/complex2015

Email submission
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Submit your abstract with 'Complex Systems 2015' in the subject line.
Please include your name, full address and conference topic.

Conference Secretariat

Irene Moreno Millan

imoreno@wessex.ac.uk

Wessex Institute
Ashurst Lodge, Ashurst
Southampton, SO40 7AA, UK

Tel: +44 (0) 238 029 3223
Fax: +44 (0) 238 029 2853

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COMPLEX SYSTEMS 2015

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The Conference aims to bring together practitioners of a variety of disciplines interested in developing and discussing new approaches for resolving complex issues that cannot be formulated using conventional mathematical or software models. Applications in modelling complex issues using multi-agent technology and similar distributed approaches, which have achieved credible results, are welcomed.

The Conference is particularly focused on methods for resolving complex issues that exhibit some of the following attributes:

Connectivity - A system consists of a large number of diverse components, referred to as Agents, which are richly interconnected.

Autonomy - Agents are not centrally controlled; they have a degree of autonomy but their behaviour is always subject to certain laws, rules or norms.

Emergence - Global behaviour of a complex system emerges from the interaction of agents and is therefore unpredictable but not random; it generally follows discernible patterns.

Nonequilibrium - Global behaviour of a complex system is far from equilibrium because frequent occurrences of disruptive events do not allow the system to return to the equilibrium between two such events.

Nonlinearity - Relations between agents are nonlinear, which occasionally causes an insignificant input to be amplified into an extreme event (butterfly effect).

Self-Organisation - A system is capable of self-organizing in response to disruptive events, a feature termed Adaptability. Self-organisation may also be initiated autonomously by the system in response to a perceived need, a feature termed Creativity.

Co-Evolution - A system irreversibly co-evolves with its environment.

High level dynamics of such systems, which are usually expressed through the frequent occurrence of unpredictable disruptive events, make conventional optimizers, batch schedulers and resource planning systems unworkable.

Complex Systems occur in an infinite variety of problems, not only in the realm of physical sciences and engineering, but encompassing fields as diverse as the economy, environment, humanities, social and political sciences. Further examples are given in the list of topics which although incomplete gives an idea of the themes to be covered by the meeting.

The conference objective is to bring together researchers, developers and users of complex systems, aiming to form a community directed at solving complex issues in novel ways.

Conference Chairmen

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Benefits of Attending

Conference Proceedings Papers presented at Complex Systems 2015 will be published by WIT Press in Volume 58 of WIT Transactions on Modelling and Simulation (ISSN: 1746-4064 Digital ISSN: 1743-355X). WIT Press ensures maximum worldwide dissemination of your research through its own offices in Europe and the USA, and via its extensive international distribution network.

Delegates will have the choice of receiving the conference book as either hard cover or digital format on a USB flash drive.

Indexing and Archiving Papers presented at Wessex Institute conferences are referenced by CrossRef and regularly appear in notable reviews, publications and databases, including referencing and abstracting services such as SCOPUS, Compendex, Thomson Reuters Web of Knowledge and ProQuest. All conference books are archived in the British Library and American Library of Congress.

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Journal Papers After the conference, presenters at Complex Systems 2015 will be invited to submit an enhanced version of their research for possible publication in the International Journal of Computational Methods and Experimental Measurements published by the Wessex Institute.

Reviews Abstracts and papers are reviewed by members of the International Scientific Advisory Committee and other experts.

Open Access Open Access allows for the full paper to be downloaded from the WIT eLibrary archives, offering maximum dissemination. Authors who choose this option will also receive complimentary access for one year to the entire WIT eLibrary.

Reduced Fee for PhD Students The Wessex Institute believes in the importance of encouraging PhD students to present and publish innovative research at their conferences. As a result, the Institute offers PhD students a much reduced conference fee.

Citations When referencing papers presented at this conference please ensure that your citations refer to **Volume 58 of WIT Transactions on Modelling and Simulation** as this is the title under which papers appear in the indexing services.

Conference Topics

A complete list of topics related to complexity issues would be infinitely long. Below are some examples. Papers on other topics related to the Conference will also be considered.

- **Complex ecological systems**
- **Complexity science and urban developments**
- **Complex energy systems**
- **Complex issues in biological and medical sciences**
- **Extreme events: natural and human made disasters**
- **Climate change**
- **Complexity of the internet-based global market**
- **Complex business processes**
- **Supply chain complexity**
- **Transportation complexity**
- **Logistics complexity**
- **Closed and open systems**
- **Attractions and chaotic systems**
- **Complex adaptive software**
- **Complexity of big data**
- **Management of complexity**
- **Global economy as a complex system**
- **Complexity in social systems**
- **Complex political systems**
- **Administrations as complex systems**
- **Complexity in engineering**
- **Complexity and environment**
- **Complexity and evolution**
- **Complexity in linguistics, literature and arts**