Estimation of REV Size and Determination of Geo-mechanical Properties of the Rock Mass in Sechahoon Anomaly XII Mine

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Abstract

Representative Elementary Volume (REV) size study was carried out for data of Sechahoon Anomaly XII mine by using a discrete fracture network and distinct element method to characterize mechanical and behavioral properties of a highly jointed rock mass. By studying on scale dependency of mechanical properties of the rock mass, REV size was determined. On the other hand, for continuum modeling of rock mass because of the inherent uncertainty in geometrical and mechanical characteristics, 39 sample models were generated stochastically based on geometry variation of joints. Uniaxial and triaxial compressive tests were performed and finally, distributions of UCS, deformability modulus, cohesion, and friction angle of rock mass were obtained. These can be used for reliability and probability investigation of the rock mass.

1. INTRODUCTION

Geometrical modeling of a fractured rock mass is defined as a mathematical description of shape, density, persistence, aperture direction, and connectivity of them. It is one of the most important issues in rock mechanics and rock engineering that can imply more uncertainty in studies [1, 2]. Numerical modeling is one of the most applicable methods to describe the geometrical properties of a rock mass. It should be noted that one of the most important duties of numerical modeling in rock mechanics is the determination of geometrical and mechanical systems of discontinuities in an explicit and implicit form [3]. To respond to this requires continuous and discontinuous numerical methods are widely utilized in rock mass behavior modeling. Continuous methods often have priority because of their simplicity and convenience but they are not in accordance with a rock mass nature [4].

Determination of laboratory properties of intact rocks is usually fast and simple. On the other hand, transformation and allocation of these properties to rock mass properties is a challenge in engineering projects. Rock engineers often assume that the discontinuity properties are weaker than intact rocks. Therefore, rock mass behavior is identified based on discontinuity behavior. This assumption may not be a universal condition. For example, if discontinuities do not have enough persistence and extension, rock mass behavior is corresponding to intact rock properties. Thus, this assumption can present a fault condition.

Rock mass as a discontinuous system in nature can have a lot of components that lead to complex problems in numerical modeling. For instance, modeling of a fractured rock mass block with 1 Km^3 volume because of a large number of blocks with various sizes, requires a very large computing memory that can greatly increase solving cost. Therefore, to limit block numbers and degree of freedom in the system, the approaches like size reduction, merging smaller components, and generating large components, solid blocks, and approximation tools (if they are allowed) can be used [5].

It is accepted that rock mass modeling is a complex problem. In order to assess the feasibility of the sublevel caving method in the Sechahoon Anomaly XII mine, determination of cavability, material flow, subsidence, and blastability of the rock mass is required. Determination of geomechanical properties of the rock mass is a prerequisite in these studies. It is obvious that achieving the geomechanical properties of the rock mass is very time-consuming and costly.

In this study, REV (Representative Elementary Volume) is introduced, and based on geometrical data of the case study, a DFN model is created. By using the DFN model and rock mass properties, REV size is determined. In the final stage, 39 geometrical models were randomly generated and implement for uniaxial and triaxial tests in order to obtain the strength and behavioral properties of the rock mass.

2. REV DEFINITION

When continuum numerical methods are used to investigate fractured medium problems like fractured rock masses, the fundamental assumption is that the discontinuous medium behavior is equivalent to the continuum medium in different scales (macroscopic and microscopic). It should be noted that continuum models were formulated in such a way that discontinuities effects have appropriately appeared in equivalent material properties. This is the homogenization process [5].

REV is defined as a tested sample with a certain size that has a sufficient number of inhomogeneity. REV can be utilized to determine whether a rock mass can behave like an equivalent continuum (figure 1) or not [6].

In other words, REV size is identified as a minimum sample size that the calculated values of properties of the rock mass are basically constant (Figure 2) [7]. Therefore, REV size shows the dependency of the fractured rock mass properties to the applied scale [8].

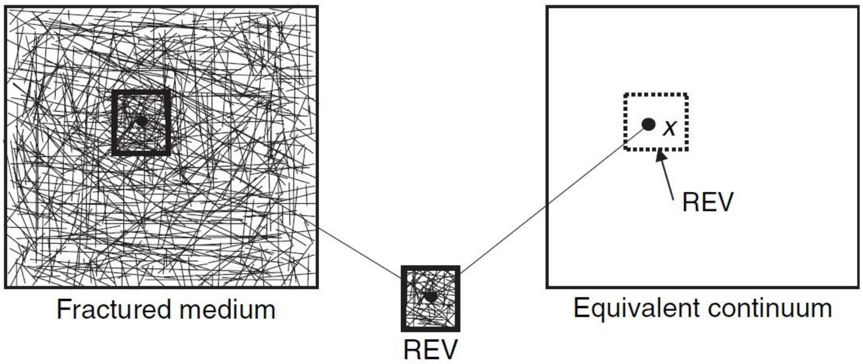

Figure 1. Fractured medium, REV and Equivalent continuum [5]

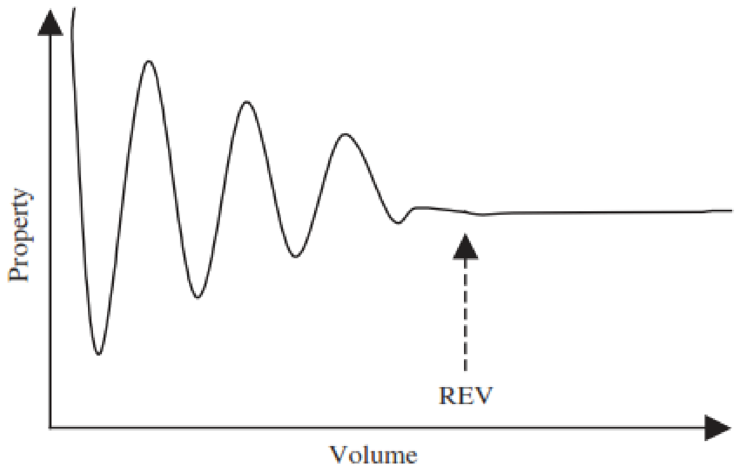

Figure 2. the REV concept [7]

Application of REV is based on this hypothesis that if $\bar{\sigma}_{ij}$ and $\bar{\varepsilon}_{ij}$ are respectively macroscopic stress and strain tensors of a fractured rock mass, microscopic stress and strain tensors are σ_{ij} and ε_{ij}, respectively. Homogenization is the transition of constitutive relations from the microscopic to the macroscopic level.

Consequently satisfying an averaging operator given by Equation 1 and 2 [9]:

$$\bar{\sigma}_{ij} = \frac{1}{V_R}\int_{V_R} \sigma_{ij}\, dv = \langle \sigma_{ij} \rangle, \qquad \bar{\varepsilon}_{ij} = \frac{1}{V_R}\int_{V_R} \varepsilon_{ij}\, dv = \langle \varepsilon_{ij} \rangle \qquad (1)$$

$$\bar{\sigma}_{ij} = \bar{k}_{ijkl}\bar{\varepsilon}_{kl} \qquad (2)$$

Where $\langle . \rangle = \frac{1}{V_R}\int_{V_R} (.)dv$ is presented as an averaging operator over volume V_R which is equal to the REV of the fractured medium. The stiffness tensor $\bar{k}_{ijkl}$ is a function of mechanical properties of the rock matrix and fractured and geometrical characteristics of fractures. Thus, the validity of homogenization depends on REV validation. Note that homogenization is not a simple averaging process. This should not only confirm the macro-micro transition in equation 1 but also no physical law should be violated.

REV is a very fundamental and applicable technique in fractured rock mass studies and was widely used in previous researches [7, 8, 10-15]. These studies were performed in 2D and 3D systems by various methods. 2D continuum studies were implemented by Kulatilac [16], Pouya and Ghoreychi [17], and Chalhoub and Pouya [18] but according to large displacements in the rock mass, it seems that discrete methods are better than continuum ones.

Schultz [19] reached this results that REV for a rock mass (basaltic rocks) can be 5 to 10 times larger than mean fracture spacing or block size. Min et.al [20] determined equivalent permeability tensor by using fractured rock mass REV. Esmaeili et.al [6] determined REV by mechanical and geometrical properties by using synthetic rock mass models in PFC software. Khani et.al [21] investigated the influences of fracture tendency on deformability and REV of fractured rock mass by numerical modeling. Wu and Kulatilak [14] reported a 3D REV for a dam using a fractured system and mechanical properties of the rock mass and then investigated the stability of a rock tunnel in that area [22]. Li and Zhang [23] calculated geometrical parameters and REV size for a crack network in the soil. Xia et.al [24] estimated REV size for blocky rock masses. Wang et.al [25] assessed an 8 m*8 m REV size of a powerhouse plant by a 2D direct shear test modeling. Farahmand et.al [26] studied the scale dependency of the geometrical and mechanical properties of jointed rock by REV method. Zhang et.al [27] determined REV size for fracture rock mass. Ni et.al [28] estimated a REV size for It should be noted that the use of REV in hydrogeology is more common than in rock engineering [29].

Note that for different conditions, REV size may be varied. The study of REV is more applicable for fractured rock masses with small sizes and large number of fractures.

3. REV DATA PREPARATION OF THE CASE STUDY

Sechahoon Anomaly XII ore deposit is located 142 Km east of Yazd, 32 Km northeast of Bafgh, 23 Km northeast of Choghart iron Mine, and 5 Km southwest of Anomaly XI. Figure 3 presents the Anomaly XII location.

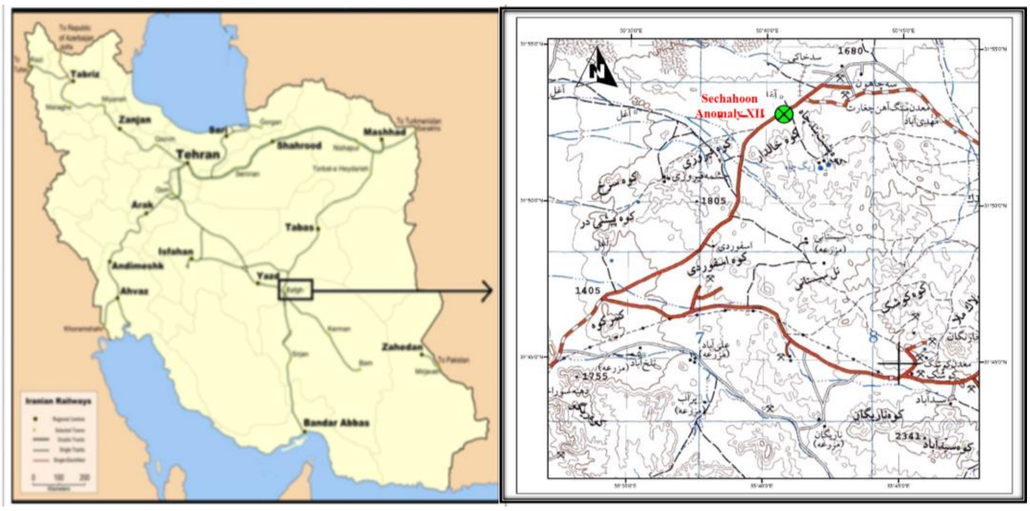

Figure 3. location of Sechahoon Anomaly XII mine

The iron deposit of this study is located in the southwest of Sechahoon Anomaly XI is on the western border of Anomaly X. This Anomaly is divided into two separate parts including the main part in depth of 350 to 490 m and the surface part. The surface of this area is about 260 hectares and is covered by quaternary sedimentary rocks.

The required data was obtained by surface (scan lines in slopes) and subsurface (exploration boreholes) investigations. Surface data was obtained from slopes of the surface part of Anomaly XII and Anomaly X (near to Anomaly 12) that contains joint set mapping and sampling for laboratory tests. Subsurface data was obtained from geochemistry holes and sampling from core boxes and taking pictures from core boxes. Fracture density (P10) was prepared by core processing software [30] (an image processing software).

To generate the model geometry, fracture density was estimated by geostatistical methods by 50 m*50 m*50 m blocks [31]. Based on the relation between RQD and P10, for P10 values greater than 20, RQD values are near to zero, thus the blocks with P10 greater than 20 were assumed as a crashed zone. For others, corresponding to each joint set frequency, P10 values were allocated. Table 1 shows input parameters based on laboratory tests for numerical modeling.

Table 1. Inputs for numerical modeling

	Property	Value
Intact rock	Density (kg/m3)	2729
	E modulus (GPa)	8.511
	Poisson ratio	0.3
	Bulk modulus (GPa)	7.093
	Shear modulus (GPa)	3.274
	Cohesion (MPa)	1.00
	Friction angle (degree)	35
Fracture	Cohesion (MPa)	0.5
	Friction angle (degree)	30

Note that the values in Table 1 were obtained by averaging all data from laboratory tests.

4. REV DETERMINATION BY UCS TEST

Fracture model geometry based on P10 and joint mapping was generated by 3DGM software [32]. Therefore uniaxial test was modeled by UDEC Itasca [33] and variation of UCS and E was investigated. Figure 4 illustrates the procedure of REV determination.

Based on geostatistical modeling and existing experiences [8, 34], the model size was selected between 2 to 20. In other words, in this study 11 models with different sizes were generated and run (figure 5). To obtain REV size, a variety of UCS and E were investigated to achieve a constant value for them. In this study, blocks were assumed deformable, and to assess the effect of scale on geomechanical properties of the rock mass, mesh size and loading rate were changed proportionally to model size.

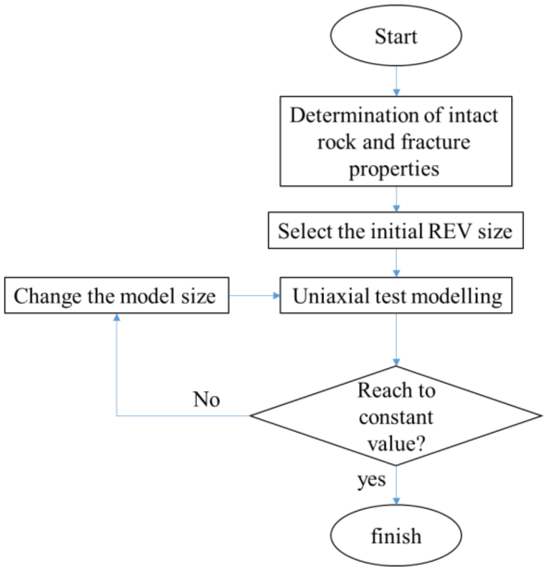

Figure 4. REV determination flowchart

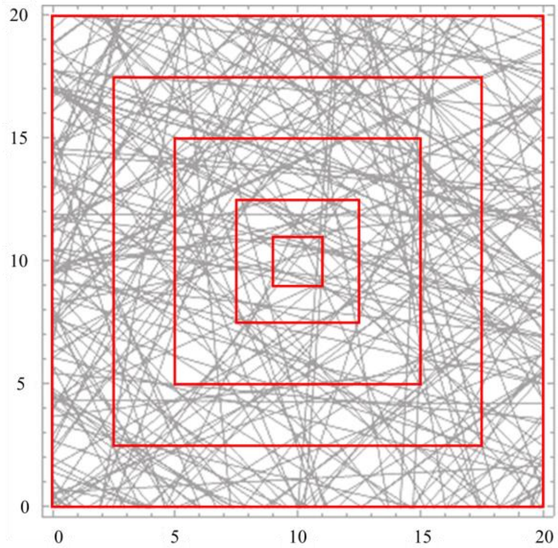

Figure 5: different model size for a study of the influence of scale on mechanical properties of rock mass

It is necessary to specify loading conditions in the UCS test after model geometry generation and applying geomechanical properties of intact rock and fractures. Based on the literature review, loads are applied on both top and bottom boundaries that lead to displacement by constant velocity together. To investigate the induced stress in the model, stress values in the center of the model, and the total sum of displacements of top and bottom boundaries was recorded. In addition, loading velocity is very small and about 1e-5 m/step.

Results of REV modeling are illustrated in Table 2 and based on them, figures 6 and 7 were generated.

Table 2. Results of mechanical rock mass characterization

Square model size (m)	Strength (MPa)	Deformability modulus (GPa)
2	1.627224	2.71204
3	1.773725	3.485973
4	1.9103	3.72974
5	3.534855	5.564528
6	1.897871	4.004479
7	1.910987	3.874113
8	2.933081	5.336392
9	2.235785	4.378752
10	2.389111	3.982963
15	2.366437	3.79591
20	2.348763	3.849105

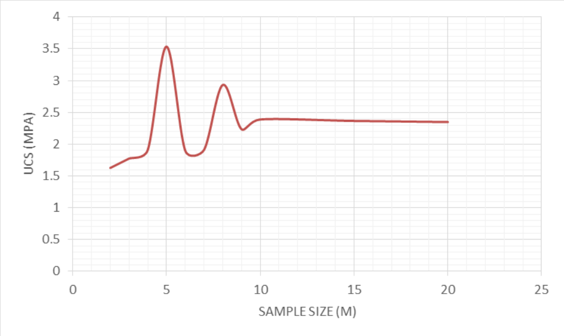

Figure 6. Influence of sample size on the UCS

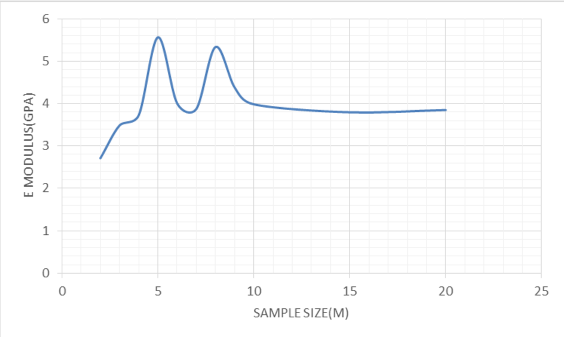

Figure 7. Influence of sample size on the E modulus

The effects of increasing sample size on UCS are illustrated in figure 6. This figure shows that UCS records some fluctuation for sample size smaller than 10 m and after that, UCS has a relatively constant value. Therefore REV size by UCS values is 10 m. In addition, this study was carried out for E modulus. Figure 7 shows that by increasing the sample size to 10 m, fluctuations of E values is reduced and reaches a constant value of 3.8 GPa. By aggregating these results, a REV size equal to 10 m was obtained.

5. STATISTICAL SIMULATION OF STRENGTH AND BEHAVIOR PROPERTIES OF ROCK MASS

Results showed that REV size is a square with 10 m length. Also, for a continuum numerical modeling, strength, and behavioral properties of rock mass are required. These properties including rock mass strength and deformability modulus and shear strength properties like cohesion and friction angle. Therefore, by using REV size and fisher distribution function of fractures, 39 samples were generated stochastically. It is obvious that the geometry of discontinuities is a major difference in these samples. In order to obtain rock mass properties, uniaxial and triaxial tests were done on all samples.

5.1. Uniaxial compressive strength

A series of UCS tests were performed on all 39 fractured rock mass samples. As we know, the UCS of rock mass plays a significant role in the stability and instability of underground spaces and cavability of the rock mass. In this study, UCS was assessed and the results of the goodness of fit test and estimation of distribution parameters for 4 distribution functions are illustrated in Table 3.

According to Table 3, between the 4 distributions, lognormal distribution has the highest P-value equal to 0.239. Then, UCS was distributed as a lognormal distribution function with location (mean) and scale (Std. deviation) equal to 0.54587 and 0.10590, respectively. The histogram of UCS data with the lognormal curve is showed in figure 8.

5.2. Deformation modulus

The deformation modulus of the rock mass is an effective parameter in rock mass condition and numerical modeling. Deformability modulus of rock mass sample was measured during uniaxial loading tests. Based on quality test tools showed in Table 4, deformation modulus has a Weibull distribution according to the highest P-value equal to 0.181.

Table 3. goodness of fit test and estimation of distribution parameters for UCS

Distribution	AD	P	Location	Shape	Scale
Normal	0.730	0.052	1.73575		0.18967
Lognormal	0.466	0.239	0.54587		0.10590
Weibull	1.671	<0.010		8.49623	1.82345
Gamma	0.528	0.196		90.01421	0.01928

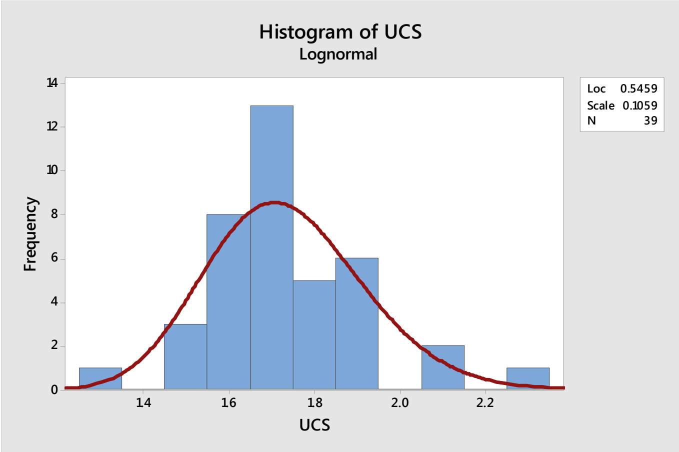

Figure 8. UCS value distribution

Table 5. goodness of fit test and estimation of distribution parameters for cohesion

Distribution	AD	P	Location	Shape	Scale
Normal	1.220	<0.005	0.48938		0.10487
Lognormal	0.619	0.100	-0.73468		0.19842
Weibull	1.687	<0.010		4.52453	0.53222
Gamma	0.790	0.042		25.06977	0.01952

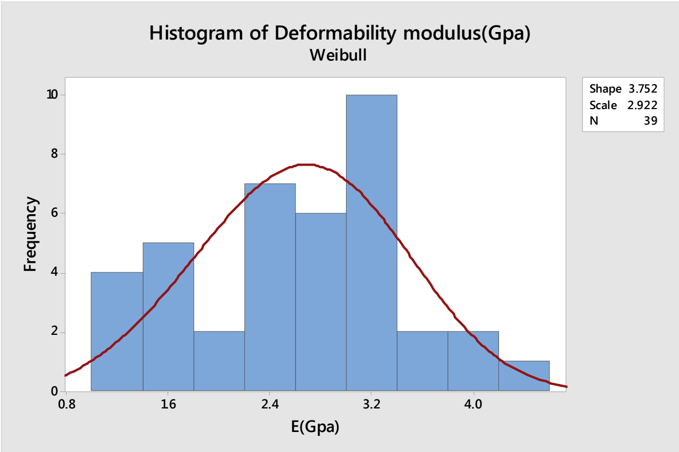

Figure 9. Deformability modulus value distribution

5.3. cohesion and friction angle

Cohesion and friction angle plays a basic role in the shear strength of rock mass. Both of them were measured by triaxial tests on rock mass samples. In order to calculate these parameters, 3 triaxial tests were implemented by 0.0, 0.1, and 0.3 MPa confining pressure. Based on these tests, the Mohr-Coulomb failure envelope was prepared. Tables 5 and 6 present the goodness of fit test and estimation of distribution parameters for cohesion and friction angle, respectively.

As shown in Table 5, P-value for lognormal distribution is the best value, thus distribution parameters of cohesion are -0.73468 and 0.19842 for location (mean) and scale (Std. deviation). The histogram and distribution curve of cohesion was presented in Figure 10.

Based on Table 6, the best distribution function for friction angle is Weibull distribution with P-value equal to 0.086, therefore the shape and scale of this equal to 7.87402 and 33.81786, respectively. Figure 11 explains the histogram and distribution curve of friction angle.

Investigation of cohesion and friction angle values leads to a linear relation between them that illustrated in Figure 12.

Table 5. goodness of fit test and estimation of distribution parameters for cohesion

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Lognormal	0.619	0.100	-0.73468		0.19842
Weibull	1.687	<0.010		4.52453	0.53222
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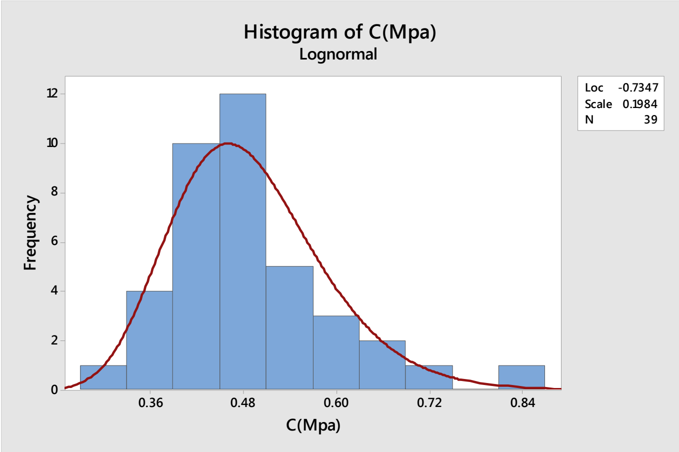

Figure 10. cohesion value distribution

Table 6. goodness of fit test and estimation of distribution parameters for friction angle

Distribution	AD	P	Location	Shape	Scale
Normal	1.394	<0.005	31.72231		5.65380
Lognormal	2.603	<0.005	3.43715		0.21628
Weibull	0.650	0.086		7.87402	33.81786
Gamma	2.153	<0.005		25.32840	1.25244

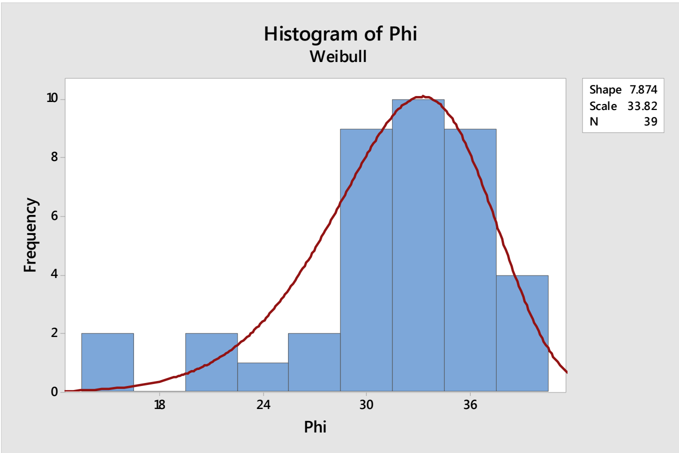

Figure 11. histogram of friction angle

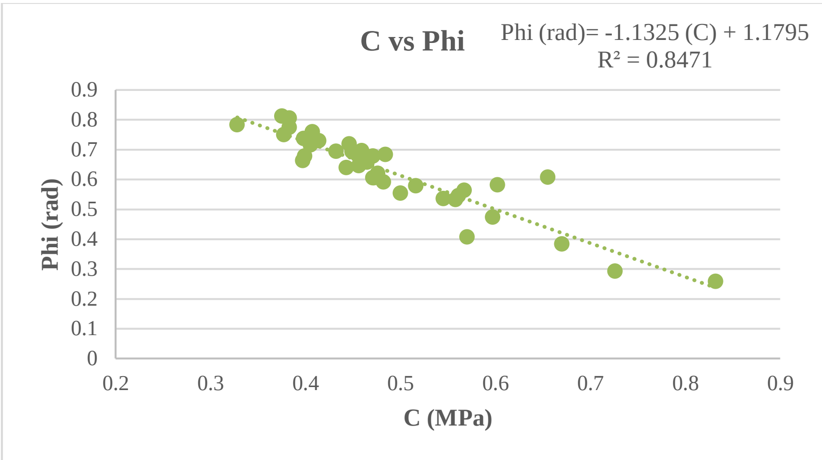

Figure 12: the relationship between cohesion and friction angle

Consequently, geomechanical characteristics of rock mass including UCS, deformability modulus, and cohesion, and friction angle with distribution function were obtained. By these results, reliability studies can be performed in a continuum numerical method.

6. SUMMARY AND CONCLUSION

Rock mass studies are not continuous because of discontinues conditions relating to fractures, also these are expensive and time-consuming. On the other hand, if rock mass has several fractures, commonly discrete numerical modeling is a complex procedure. One of the best approaches to exceed this problem is using REV and calculating continuum equivalent parameters for continuum modeling without considering the distribution of fractures. By this approach, rock mass characteristics are obtained. Table 7 illustrates the statistical parameters of rock mass properties.

Table 7. descriptive statistical of rock mass properties

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
E	39	1.248	4.317	2.635	0.798	-0.010	0.378	-0.417	0.741
Phi	39	14.460	39.051	31.722	5.653	-1.439	0.378	2.219	0.741
C	39	0.328	0.832	0.489	0.104	1.309	0.378	2.047	0.741
UCS	39	1.346	2.327	1.735	0.189	0.951	0.378	1.783	0.741

This paper presented a quantitative procedure to determine REV size for Sechahoon Anomaly XII. Field data is prepared by surface and subsurface studies. The conclusions of this study are as follows:

- The impact of scale on strength and deformability of rock mass was successfully characterized and REV size was estimated by uniaxial compressive test on models with different sizes. According to geometrical properties of the rock mass, a minimum REV size was determined to equal to 10 m×10 m by UCS and deformability modulus variability.
- Continuum modeling is an appropriate tool for the feasibility study of rock engineering projects. Reliable input data in continuum models is an important key for this technique. Therefore, equivalent data can be characterized using discontinuum modeling.
- Because of the nature of rock mass data, input data for the continuum model is not deterministic, thus for reliable modeling and obtaining a better vision of rock mass behavior, the distribution function of input data is necessary. Therefore, 39 sample geometries based on spacing, dip, and dip direction of joints were generated stochastically. By performing uniaxial and triaxial compressive tests on all samples, a data set of continuum input parameters has resulted.
- By analyzing the output of these tests, the distribution function of the parameters was defined. These results can be used for the continuum modeling of highly jointed rock masses. The importance of these can be used as input values for reliability studies and statistical simulations.

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