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Investigating the Anisotropic Equivalent Modeling of Discontinuous Media Around Tunnel

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Abstract: The prediction of the deformations and stresses around excavations in rock masses is a research area of interest to engineers who perform rock excavations in various fields. There is almost no comprehensive and precise available method for rock mass modeling because rock masses have natural discontinuity of different sizes, orientations and strengths. Exploration of all joint systems and investigation of their mechanical properties and exact modeling of them is impossible in practice. Elastic modulus, friction angle and cohesion strength of rock mass are the most important input parameters of continuum equivalent medium for the numerical analyses and to predict of deformations and stresses around excavations. Performing in-situ tests is the most accurate way for obtaining elastic modulus but it is very time-consuming and expensive; consequently, some empirical relations based on classification systems of rock especially RMR system have been offered in order to estimate this parameter. But these classification systems are not sufficiently sensitive to variation of joint spacing and system. Also the empirical relations have not considered the effect of anisotropy. For estimation of rock mass strength parameters (C &φ), some empirical relations have also been offered by different researchers. Also during recent years, equivalent continuum approaches, which attribute resultant of intact rock and joint properties to rock masses, are considered. In this study, elastic modulus, friction angle and cohesion strength of rock mass around tunnel have been calculated for media with one and two joint sets, different spacing and inclinations using numerical method. Making continuous medium as equivalent of discontinuous medium around tunnel has been done with two discontinuous and continuous medium programs using a numerical method. Once discontinuous medium was modeled with intact rock and joints parameters by discrete element method, then medium around tunnel was modeled as continuous with equivalent parameters using finite element method. Finally, equivalent continuum properties have been obtained based on intact rock and joint strength properties, spacing and inclination of joints. Also the effect of tunnel diameter on rock mass modulus was investigated.

Key words: Rock mass · Intact rock · Joint set · Continuous equivalent medium · Discontinuous medium · Numerical method

INTRODUCTION

Numerical modeling is a common method for the prediction of stresses around tunnel, the reaction of rock mass to excavation and their analyses. Numerical simulation of underground excavations is difficult and complex in discontinuous media. Hence using equivalent media has become very comon in numerical modeling. Rock masses in nature contain numerous discontinuities in the form of cracks, joints, faults, bedding planes, etc. Various continuum equivalent models of discontinuum models have been proposed and used to assess the stability of rock tunnels since the beginning of 1970. In general, numerical models on tunnels in discontinuous

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rock masses can be categorized into three groups of discrete models, equivalents models and hybrid models [1].

Elastic modulus, friction angle and cohesion strength of rock mass are the most important input parameters of continuum equivalent medium for the numerical analyses and prediction of deformations and stresses around excavations. Elastic modulus of rock mass is simply the stress to strain ratio during the loading of rock mass that includes only elastic behavior. Elastic modulus of rock mass can be obtained via three methods of insitu tests, laboratory tests and empirical relations. The insitu tests include: plate jack, pressure tunnel, borehole, triaxial pressure, radial jack and goodman jack. The laboratory tests include: triaxial pressure, uniaxial pressure and resonant column device [2]. They both are very time-consuming and expensive and also have executive problems. Consequently using empirical relations and methods for defining elastic modulus has been considered. In recent years, different computer-based analytical methods have been presented that are based on numerical methods and define stress and displacement condition around tunnel with different moods. In this paper, rock mass strength properties have been estimated from intact rock and Discontinuities properties by numerical method in discrete element and finite element software.

In equivalent continuum approach, the rock mass is treated as a continuum with equal properties and equal input data for the strength and deformability properties, which define an elastic or elasto-plastic constitutive relation for the medium. But in discontinuum approach the rock mass is represented as a discontinuum and most of the attention at the design stage is devoted to the characterization of the rock elements, the rock joints and discontinuities [3]. Except for numerical modeling of equivalent medium, a set of empirical relationships derived from a statistical analysis of experimental data were offered to estimate the strength of rock mass by Roy (1993), Arora (1987), Yaji (1984), Brown and Trollope (1970) and Einstein and Hirschfield (1973). In finite element modeling, the jointed rock properties are represented by these empirical relationships, which express the properties of the jointed medium as a function of joint factor and the properties of the intact rock [4]. Using empirical methods brings many limitations in the design of underground excavations and can only utilize them in primary stages of design. Application of these methods is limited to simple boundary conditions and geometry of problems. In addition to numerical analysis methods are advanced design methods that have been introduced to engineers' society and have been used in recent decades [5].

In this paper, equivalent elastic modulus, friction angle and cohesion strength of rock mass around tunnel were estimated based on spacing and system of joints using numerical method and then these parameters were obtained as a function of joint set inclination and spacing. Therefore, modeling has been done in discontinuous and continuous medium by UDEC 4.0 and PLAXIS 8.2 software respectively. UDEC is a two-dimensional numerical program based on the distinct element method for discontinuum modeling. The discontinuous medium is represented as an assemblage of discrete blocks and the discontinuities are treated as boundary conditions between blocks [6]. PLAXIS is a finite element package intended for the two-dimensional analysis of deformation and stability in geotechnical engineering and is often used in continuous media of soil and rock [7]. Whenever the number of discontinuities increases in rock mass, the general behavior of rock mass has an inclination for becoming isotropic. Rock mass with four or more discontinuity sets is considered as an isotropic mass [8]. But here the medium has one or two joint sets and regarded as anisotropic medium.

Anisotropy in a rock mass resulting from preferentially orientated structural features (micro and macro scale) around the boundary of an underground opening affects the extent and shape of low confinement zones around the boundary of an excavation and therefore directly influences the location and depth of stress driven rock mass degradation which is a tensile driven process. When structural features (micro and/or macro), especially foliations are present in a rock mass, the strength is effectively reduced largely due to tensile strength heterogeneity depending on the orientation of structural features with respect to the excavation boundary (i.e. loading direction relative to the anisotropy). In general, anisotropy:

- Affects the strength of the rock mass depending on loading direction;
- Causes a non-uniform stress state and displacement around the boundary of an underground opening;
- Creates a non-uniform depth of failure; and
- Allows for stress-induced failure (near wall degradation) to possibly occur at relatively low stress levels and under unexpected stress conditions [9].

Table 1: Empirical relations for defining elastic modulus of rock mass

Used relationship	Reference	Elucidation
$\pi(\frac{RMR}{100}))][1 - Cos(E_m = 0.5E_r)$	[10]	Mitri et al relationship
$E_m = 0.3H^{\alpha} * 10(\frac{RMR - 20}{38})$	[10]	Verman *et al* relationship (α is a coefficient between 0.16 to 0.3)
$E_m = H^{0.2} * Q^{0.36}$	[10]	Singh relationship

Therefore, unlike the empirical relations that estimate one elastic modulus for rock mass, in this paper horizontal and vertical moduli have been calculated separately. This research contains two parts: in the first part elastic modulus of rock mass and in next part friction angle and cohesion strength have been estimated.

Empirical Relations for Defining Elastic Modulus of Rock Mass: First, elastic modulus of rock mass has been calculated with some empirical relationships that have been offered by different researchers previously. (Table 1).

Then obtained modulus by numerical method has been compared with these values. Selection criterion of these relationships is wide range of application and their input parameters. The number of input parameters of these relationships is minimal and elastic modulus of rock mass is calculable with existing parameters in this paper. These relations have utilized three important parameters, namely RMR[1], Q and H. RMR and Q, which are convertible to each other using the following relation (equation 1). H signifies the height of tunnel overload [11].

$$RMR = 9 \ln Q + 44 \quad (1)$$

Basic parameter in these relations for modulus calculation is RMR. That is the sum of six parameters, namely (a) the uniaxial compressive strength of the intact rock; (b) RQD; (c) discontinuity spacing; (d) condition of discontinuity surfaces; (e) groundwater conditions; and (f) the orientation of discontinuities relative to the engineered structure. In this paper uniaxial compressive strength, groundwater conditions and condition of discontinuity surfaces have assumed to have constant rates of 12, 15 and 21 respectively. Also rate of RQD as for rather partial variations of spacing in all investigated cases is 20. With these explanations and considering the negative effect of the orientation of discontinuities, the value of RMR varies from 66 to 83. The effect of discontinuities orientation is as follows: their inclinations are divided into three ranges: 0-20, 20-45 and 45-90. Each range has a particular negative effect in tunnel [11]. In the numerical method offered in this paper, every change in inclination changes the equivalent modulus of rock mass.

Modeling Procedure: This study was an attempt to obtain rock mass equivalent parameters around tunnel in a jointed medium via numerical method. So both discontinuous medium (a medium contains discontinuities in the form of cracks, joints, faults, bedding planes, etc) and continuous medium (a medium contains no discontinuities and is only composed of soil or rock body) were modeled.

First, modeling in UDEC program was done. One joint set models have a dimension of 60m wide and 60m high. A 10m-diameter tunnel is placed at the center of them. For considering the effect of joints spacing, the inclination of joints was set fixed and for considering the effect of inclination of joints the joints spacing was fixed. In the initial models, one joint set with constant and arbitrary inclination of 30 degrees was modeled and just joints spacing changed from 0.25m to 5m. In the next step joints spacing were constant and 0.5m and joints inclination changed from 0 to 180 degrees. This variation has an interval of 10 degrees. In all of the two joint sets models, joints spacing was fixed (0.5m), but joints inclination and the angle between the two joint sets were variable. Two joints sets models have a dimension of 40m wide and 40m high. In Figure 1 an example of one joint set has been demonstrated.

For obtaining elastic modulus of rock mass after models were made in UDEC, the tunnel is excavated once and values of vertical displacements at crown and floor of tunnel and horizontal displacements at right and left of tunnel are measured. Then in PLAXIS program we change elastic modulus so that the displacements around tunnel become equal with the values of UDEC and vertical and horizontal moduli obtained in PLAXIS separately. Examples of these models have been demonstrated in Figures 2-4. In the first stage, verical and horizental displacements around tunnel after excavation in UDEC program were measured. Figure 2 shows an example of these models.

[1]Rock Mass Rating

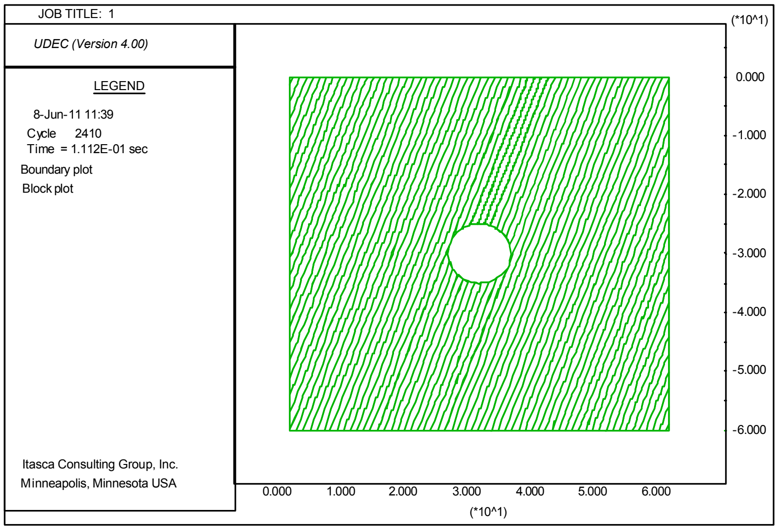

Fig. 1: A made model in UDEC with one joint set, 1m spacing and inclination of 70 degrees

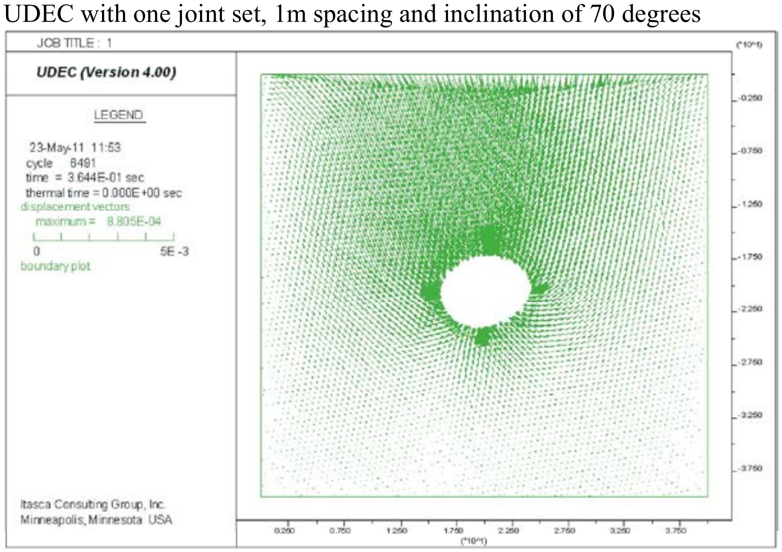

Fig. 2: Displacements around tunnel in two joint sets model of UDEC with inclination 10 and 80

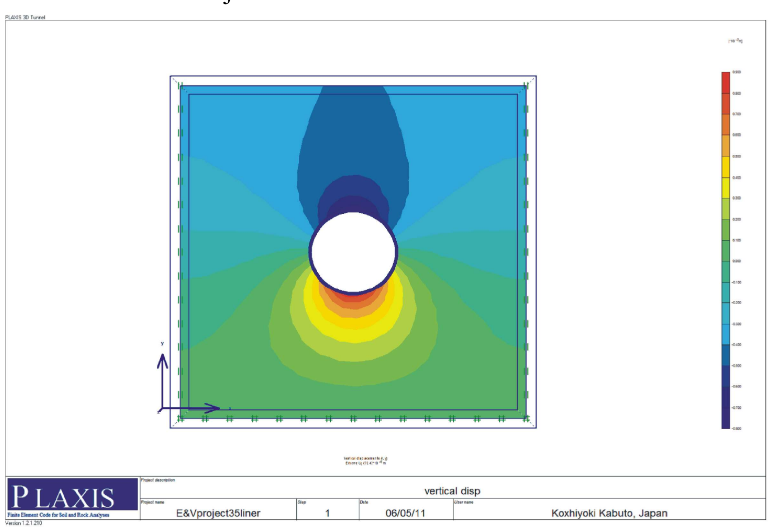

Fig. 3: Vertical displacement in continuous model of PLAXIS for the estimation of rock mass vertical modulus

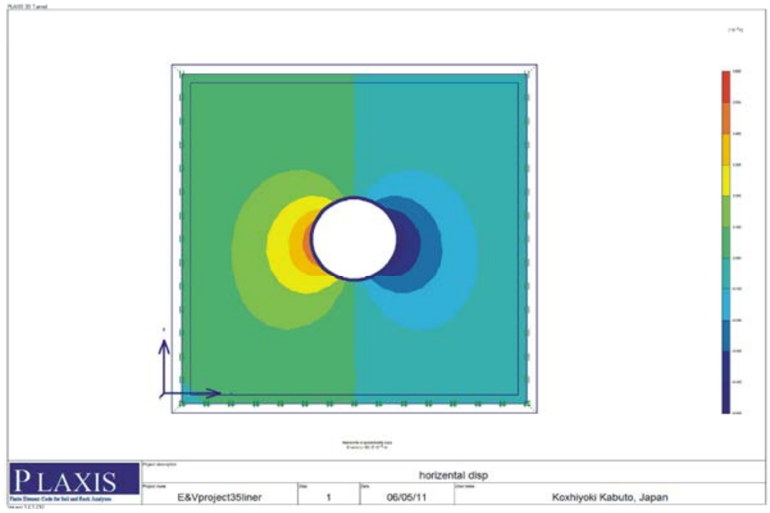

Fig. 4: Horizental displacement in continuous model of PLAXIS for estimation of rock mass horizantal modulus

Table 2: Mechanical properties of intact rock and joints

Parameter	Value	Parameter	Value
Elastic modulus (E)	27GPa	Rock density (□)	2600Kg/m^3
Friction angle (□)	40 degree	Joint shear stiffnes (Jks)	8.92GPa/m
Cohesion strength	3 Mpa	Joint normal stiffnes (Jkn)	15.1GPa/m
Poisson ratio (□)	0.25	Joint friction angle	38 degree
Uniaxial compressive strength (σc)	150Mpa	Joint cohesion	2MPa
Height of tunnel overhead (H)	15m	Joint dilation angle	0 degree

Then in PLAXIS program elastic modulus was changed so that the displacements around tunnel in the continuous medium become equal with the values of discontinuous medium. Vertical displacement in a continuous model of PLAXIS for the estimation of rock mass vertical modulus has been represented in Figure 3.

Horizental displacement in the same continuous model of PLAXIS for the estimation of rock mass horizental modulus has been represented in Figure 4.

In the stage of obtaining the elastic modulus, linear elastic model has been selected in two programs. In order to achieve the most resemblance to the real case and to prevent failures in the model and the slipping and falling rock wedges around tunnel in the UDEC models, a support of shotcrete was applied. To assimilate model conditions in the two softwares, the same support was applied in PLAXIS. Insitu stresses are applied as follows: the vertical stress varies with depth based on density. It varies from zero at ground surface to about 0.5 MPa at the center and 1 MPa at the bottom of models. K value, or the ratio of horizontal to vertical stresses, assumed to be 1; meaning that stress state is hydrostatic. Totally, 25 one joint set models and 117 two joint sets models were made in UDEC and for each model in UDEC equivalent models created in PLAXIS. Mechanical properties of intact rock and joints are summarized in Table 2. Only variable parameters in models are spacing and inclination of joints.

Also the effect of tunnel diameter on elastic modulus of rock mass has been investigated. To do this, 12 from previous models were run with a 5m-diameter tunnel. Then obtained moduli from these models were compared with moduli from original models.

In the second part, for obtaining the rock mass strength parameters namely C and φ, the previous steps and models were replicated exactly using obtained elastic modulus except that base parameter for making equivalent meduim were plastic zone radius, support bending moment, support axial force and shear force. Also material model is mohr-coulomb model (perfect-plasticity) and jointed rock model in UDEC and PLAXIS respectively. In fact, jointed rock model is the same as mohr-coulomb model and has the advantage that uses vertical and horizontal moduli separately. It is better to import two moduli into the software because the medium is completely anisotropic. We utilized the elastic moduli obtained in the first stage to estimate C and φ. Because of the change in joints system this parameter also changes at each model. When the medium is anisotripic and the two elastic moduli are defined, the shear modulus is obtained using equation 2. [12].

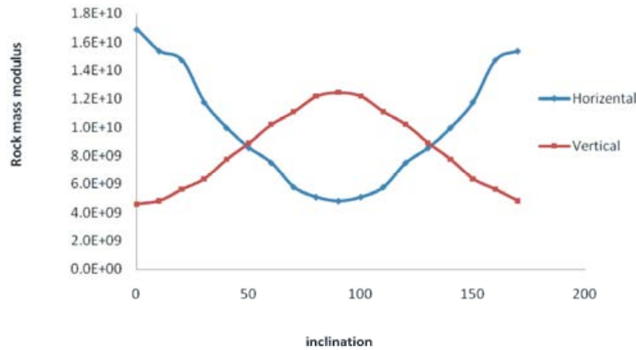

Fig. 5: Relationship between vertical and horizontal modulus of rock mass and joint inclination

$$\frac{1}{G'} = \frac{1}{E} + \frac{1}{E'} + 2\frac{\nu'}{E'} \qquad (2)$$

Therefore only two parameters, i.e., cohesion and friction angle remained unbeknown. We varied the values of these parameters so that the radius of plastic zone after excavation was equal with the models of UDEC. Therefore, for each model that had a specific inclination and spacing in UDEC, equivalent C and φ is obtained. To find the best C and φ we must refer to other parameters in the model, namely bending moment of support, axial and shear force of support. Finally for each model best C and φ has been selected.

Modeling of Elastic Modulus and Comparing with Empirical Relationship: To investigate joint inclination, joint spacing was constant and equal to 0.5m and joint inclination varied from 0 to 180 degrees. Because of the symmetry effect in models, obtained moduli with the inclination of 0 to 90 degrees equal the inclination of 180 to 90 degrees exactly. The results have been summarized in Figure 5.

Increase in joint inclination leads to an increase in vertical modulus and decrease in horizontal modulus. The maximum of vertical modulus is 12.44 Gpa and minimum of that is 4.6 Gpa that are 0.46 and 0.17 of intact rock elastic modulus respectively. Also the maximum of horizontal modulus is 16.9 Gpa and minimum of that is 4.8 Gpa that are 0.63 and 0.18 of intact rock elastic modulus respectively. According to the Figure 5 in angles of 48 and 132 degrees, the vertical and horizontal modulus become equal and the medium will be isotropic.

Then two joint sets models were made. In these models joints spacing were fixed (0.5m) and just angle between two joint sets was changed. The angle between first joint set and horizon is α and the angle between second joint set and horizon is β. In each series of models, inclination of the first joint set was constant (α) and the second (β) changed from 0 to 180 degrees. 117 models were run in two joint sets models totally and vertical and horizontal moduli were calculated separately. Results have been brought in Figure 6 and 7.

In two joint set models as expected, when joints are more horizontal, vertical modulus is less and horizontal modulus is more. The more vertical the joints are, vertical and horizontal moduli will be higher and lower respectively. Most vertical elastic modulus in two joint set models is correspond to inclination of 80 and 90 degrees with value of 8.47 Gpa that is 0.31 of intact rock modulus and the least vertical elastic modulus in these models is correspond to degrees of 0 and 10 with value of 1.985 Gpa that is 0.07 of intact rock modulus. Most horizontal elastic modulus in two joint set models is correspond to inclination of 0 and 10 degrees with value of 10.2 Gpa that is 0.37 of intact rock and least horizontal elastic modulus in these models is correspond to degrees of 80 and 90 with value of 2.38 Gpa that is 0.09 of intact rock.

In the next step, to investigate joint spacing effect on elastic modulus of rock mass, all parameters were selected based on Table 2 and joint spacing was changed from 0.25m to 5m. Joints inclination has been fixed (30) degrees in this section. Results have been summarized in Figure 8.

Increase in joint spacing results in an enhancement in vertical and horizontal moduli. The curves of horizental and vertical moduli tend to be lateral at joint spacing of more than 3 meters. At 5 meters joint spacing, horizental modulus is 0.8 of intact rock and vertical modulus is 0.59 of intact rock. Obtained moduli by numerical method and empirical relationships for joints with different inclinations have been compared in Table 3.

Then Obtained equivalent moduli by numerical method have been compared with obtained moduli by before mentioned relationships for different joint spacing and have been represented in Table 4. The unit for all these values is Giga pascal.

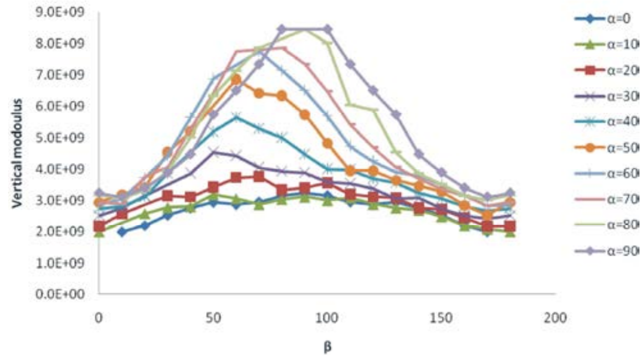

Fig. 6: Relationship between vertical elastic modulus and inclination of two joint sets

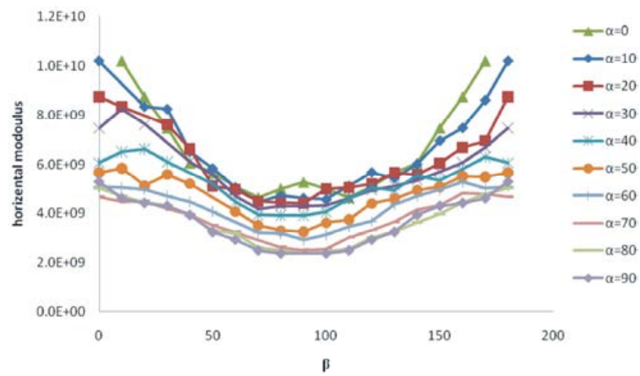

Fig. 7: Relationship between horizental elastic modulus and inclination of two joint sets

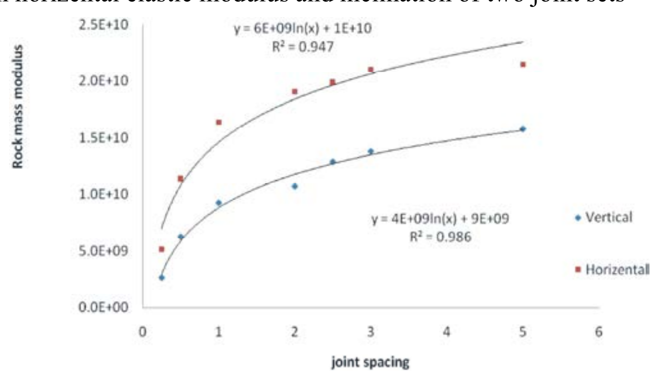

Fig. 8: Relationship between vertical and horizontal modulus of rock mass and joint spacing

Table 3: Obtained moduli from numerical method and empirical relationships (variable inclination)

Joints states	Mitri *et al.* relation	Verman's relation	Singh's relation	Vertical modulus Numerical method	Horizental modulus numerical method
One joint set with spacing of 0.5m and inclination of 0 degree	23.1435	14.6361	6.0725	4.6	16.9
One joint set with spacing of 0.5m and inclination of 10 degree	23.1435	14.6361	6.0725	4.825	15.4
One joint set with spacing of 0.5m and inclination of 20 degree	23.1435	14.6361	6.0725	5.615	14.8
One joint set with spacing of 0.5m and inclination of 30 degree	23.1435	14.6361	6.0725	6.26	11.4
One joint set with spacing of 0.5m and inclination of 40 degree	23.1435	14.6361	6.0725	7.75	9.97
One joint set with spacing of 0.5m and inclination of 50 degree	20.6421	9.5766	4.5895	8.9	8.56
One joint set with spacing of 0.5m and inclination of 60 degree	20.6421	9.5766	4.5895	10.2	7.51
One joint set with spacing of 0.5m and inclination of 70 degree	20.6421	9.5766	4.5895	11.2	5.77
One joint set with spacing of 0.5m and inclination of 80 degree	20.6421	9.5766	4.5895	12.19	5.08
One joint set with spacing of 0.5m and inclination of 90 degree	20.6421	9.5766	4.5895	12.44	4.8

Table 4: Obtained moduli from numerical method and empirical relationships (variable spacing)

Joints states	Mitri *et al.* relation	Verman's relation	Singh's relation	Vertical modulus numerical method	Horizental modulus numerical method
One joint set with spacing of o.25m and inclination of 30 degree	23.1435	14.6361	6.0725	2.67	5.15
One joint set with spacing of o. 5m and inclination of 30 degree	23.1435	14.6361	6.0725	6.26	11.4
One joint set with spacing of 1m and inclination of 30 degree	24.6648	19.8154	7.4170	9.27	16.4
One joint set with spacing of 2m and inclination of 30 degree	24.6648	19.8154	7.4170	10.73	19.1
One joint set with spacing of 2.5m and inclination of 30 degree	25.9218	26.8276	9.0591	12.9	19.9
One joint set with spacing of 3m and inclination of 30 degree	25.9218	26.8276	9.0591	13.8	21.1
One joint set with spacing of 5m and inclination of 30 degree	25.9218	26.8276	9.0591	15.8	21.5

Table 5: Cohesion strength and friction angle of rock mass with one joint set and variable inclination

Joint inclination (Degree)	Horizental elastic modulus (Pa)	Vertical elastic modulus (Pa)	Shear modulus (Pa)	Cohesion (KPa)	Friction angle (Degree)
0	1.690E10	4.600E9	3.266E9	119.6	36
10	1.540E10	4.825E9	3.282E9	116.5	36
20	1.475E10	5.615E9	3.574E9	115	36
30	1.178E10	6.363E9	3.515E9	64	35
40	9.970E9	7.750E9	3.578E9	40	33
50	8.560E9	8.900E9	3.504E9	47	34
60	7.505E9	1.020E10	3.568E9	97	35
70	5.770E9	1.110E10	3.242E9	103.5	36
80	5.083E9	1.219E10	3.127E9	106	36
90	4.800E9	1.244E10	3.040E9	97.5	37
100	5.083E9	1.219E10	3.127E9	106	36
110	5.770E9	1.110E10	3.242E9	103.5	36
120	7.505E9	1.020E10	3.568E9	97	35
130	8.560E9	8.900E9	3.504E9	47	34
140	9.970E9	7.750E9	3.578E9	40	33
150	1.178E10	6.363E9	3.515E9	64	35
160	1.475E10	5.615E9	3.574E9	115	36
170	1.540E10	4.825E9	3.282E9	116.5	36

As expected, increase in joint spacing leads to an enhancement in vertical and horizontal moduli. Values of horizontal modulus are more than those of vertical modulus generally.

Results of Rock Mass Strength Modeling: For considering the effect of joint inclination on rock mass strength parameters in one joint set models, in this step, joint spacing was constant and 0.5m and joint inclination varied from 0 to 180 degrees. It is clear that in one joint set state, inclinations of 0 to 90 degrees are symmetry of 180 to 90 degrees. C and φ values of symmetric inclinations are equal together. These results have been summarized in Table 5.

As the results obviously show, inclination of 40 degrees and its symmetry namely 140 degrees have the least values of C and φ and are the most critical state of rock mass with one joint set. Bray's relationship was used to investigate this issue. With the equation 3, support pressure or internal pressure of the tunnel which prevents any slip and falling, can be calculated [13].

$$P_b = (N_1 p_1 + N_2 p_2), \{\frac{\tan|\psi|}{\tan(|\psi| + \varphi_j)}\} \quad (3)$$

The first part of the relationship includes N and P. Indeed first part is the tangential stress in any point around tunnel. The point that is considered for comparison was spotted at tunnel crown. ψ is the angle between joint set with external surfaces of tunnel. According to this relationship most critical state occurs in angle of 30 degrees. Most critical state is the state that internal pressure is at its maximum level. It differs about 10 degrees from the estimated angle. This variance is related to the place of handling point that is a spot at tunnel crown probably. While the most unstable place may be a point other than tunnel crown.

For considering the effect of joint spacing on rock mass strength parameters in one joint set models, all parameters were selected based on Table 2 and joint spacing was varied from 0.25m to 5m. Inclination of joints in this step was constant and 30 degrees. Finally for each model, values of C and φ were obtained. The Results have been summarized in Table 6.

Table 6: Cohesion strength and friction angle of rock mass with one joint set and variable joint spacing

Joint spacing (M)	Horizental elastic modulus (Pa)	Vertical elastic modulus (Pa)	Shear modulus (Pa)	Cohesion (KPa)	Friction angle (Degree)
5	2.15010	1.580E10	7.515E9	155	38
3	2.105E10	1.380E10	6.958E9	122	38
2.5	1.990E10	1.290E10	6.540E9	100	37
2	1.910E10	1.073E10	5.823E9	102	36
1	1.640E10	9.270E9	5.017E9	90	36
0.5	1.140E10	6.260E9	3.433E9	75	35
0.25	5.150E9	2.670E9	1.502E9	18	25

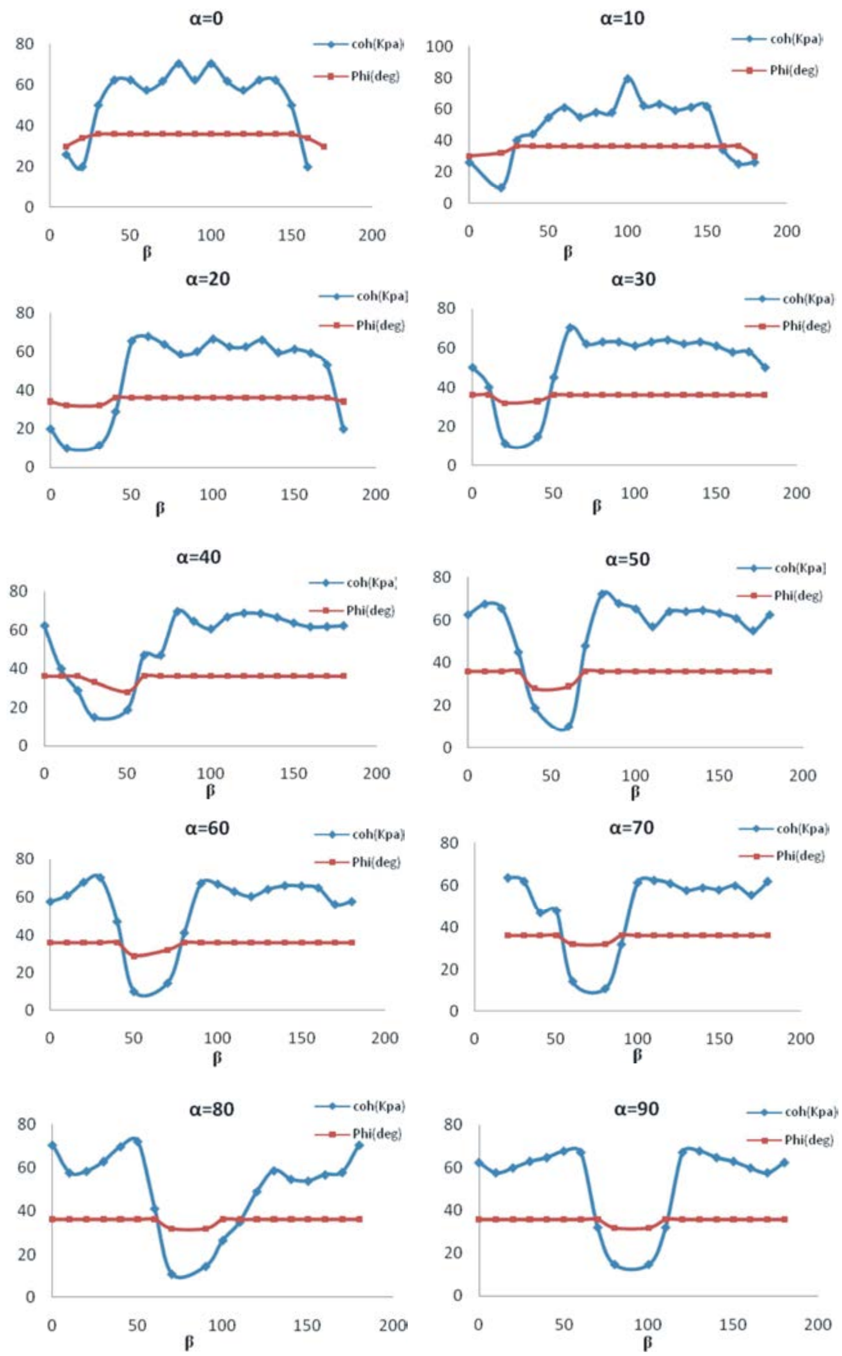

Fig. 9: Relationship between the inclination of joints with equivalent strength parameters of rock mass

As expected, reduction in joint spacing leads to a decrease in equivalent medium strength. In other word, values of C and φ diminish. In the most stable condition, i.e., joint spacing of 5m, rock mass friction angle is very close to intact rock but rock mass cohesion in this state has a low value.

Then modeling of rock mass with two joint sets was done. In these models joints spacing was fixed (0.5m) and only the angle between two joint sets was changed. Therefore in each series of models, inclination of one joint set was constant and the other varied from 0 to 180 degrees. The angle between first joint set and horizon is α and the angle between second joint set and horizon is β. Results have been shown in Figure 9. In each graph, the inclination of constant joint set (α) has been intercalated at caption part and curves represent variations of cohesion (at Kilo Pascal) and friction angle (at degree) versus inclination variations of other joint set (β).

In two joint set models, friction angle of 35-37 degrees the most appropriate value for making equivalent medium because in these friction angles, bending moment, axial force and shear force have the closest values to the discontinuous state. Therefore, in most equivalent states friction angle of 36 degrees has been selected except when the angle of 36 degrees was a high value, in which case however much we reduce the cohesion, still equivalent medium has more strength than discontinuous medium. Overally, because of the joint effect, shear force and bending moment values in discontinuous medium are much greater than equivalent continuous medium but axial force values in two media are equal approximately. As is clear from the graphs, cohesion values have a minimum zone where the angle between the two joint sets is less than a certain amount. In this zone, C and φ values reduce significantly. Then the angle between two joint sets in these models is too important.

CONCLUSIONS

In this study, elastic modulus, friction angle and cohesion strength of rock mass around tunnel were calculated for media with one and two joint sets, different spacing and inclinations using numerical method. Making continuous medium as equivalent of discontinuous medium around tunnel was done with two discontinuous and continuous medium programs using a numerical method.

Numerical method presented in this study for estimation of elastic modulus is more sensitive than empirical relations to joint spacing and inclination. To obtain of horizental modulus, For joints with inclination of more than 70 degrees, Singh's relation and for joints with inclination of 0 to 60 degrees, Verman's relation gives closer values to numerical method and to obtain of vertical modulus, For joints with inclination of 0 to 40 degrees, Singh's relation and for joints with inclination of more than 50 degrees, Verman's relation gives closer values to numerical method. Also the estimation of strength parameters by this method is more sensitive than empirical relations including Hoek-Brown's relation to joints inclination. Variation in joints inclination affects strength parameters of equivalent medium clearly, whereas in Hoek-Brown's relation joint inclination has a little effect on equivalent medium strength via geological strength index (GSI).

Tunnel diameter affects on value of equivqlent modulus. Models with a 5m-diameter tunnel showed that decrease in tunnel diameter leads to an increase in elastic modulus of rock mass. Thus, for a tunnel with smaller diameter the rock mass shows more intact behavior. Amount of this increment is clearly related to the angle between two joint sets. When the angle between the two joint sets is small, a decrease in tunnel diameter from 10m to 5m will make the elastic modulus of rock mass increase 4 times. But when the angle between two joint sets increases to 90 degrees, this increment in modulus will be just 2 times.

Maximum and minimum vertical elastic moduli in the two joint sets models correspond to 80-and-90-degree angles with the value of 8.47Gpa (0.31 of intact rock) and 0-10-degree angles with the value of 1.985Gpa (0.07 of intact rock) respectively. Maximum and minimum horizontal elastic moduli in two joint sets models are related to 0-10-degree angles with value of 10.2Gpa (0.38 of intact rock) and 80-90 degree angles with the value of 2.38Gpa (0.09 of intact rock) respectively.

In rock mass with one joint set, the most critical state of joint inclination (minimum C and φ values) is the angle of 40 degrees and the most stable state is horizontal joints. Bray's relation almost confirms these angles. In two joint sets states, the most effective parameter on equivalent medium is the angle between two joint sets so that when this angle is less than 20 degrees, plastic zone radius around tunnel increases strongly and then strength parameters decrease. For example, the most unstable state in the two joint sets models is the angles of 40 and 50 degrees in which the angle between them is 10 degrees. When the angle between the two joint sets is more than 20 degrees, rock mass strength parameters have high values and this angle and joint inclination do not have much effect on equivalent medium strength.

In the two joint sets models, the best equivalent friction angle that was estimated using bending moment, axial force and shear force was 36 degrees, that is, 10% reduction in comparison with the intact rock friction angle. For cases that the angle between the two joint sets is too small (less than 20 degrees) this rule does not hold true.

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