Mechanical Properties of Weak Rock for Tunnel Construction in Korea

Hyun-Seok Yun [(1)], Seong-Woo Moon [(1)], Gyu-Jin Song[(1)] and Yong-Seok Seo[(1)*]

(1) Dept. of Earth and Environmental Sciences, Chungbuk National University, Korea
E-mail:ysseo@cbu.ac.kr

Abstract

This study analyzed the mechanical properties of rock mass classified into class Ⅴ by the RMR system and fault zone distributed in Korea to understand the geotechnical parameters of weak rocks. The mechanical properties data of weak rocks were collected from established design cases and literature. The mechanical properties of fault zone are distributed in their ranges as follows; unit weight 17.3~26.3 kN/㎥, cohesion 0.036~260 kPa, internal friction angles 14.7~44.1°, moduli of deformation 3.5~800 MPa, and Poisson's ratios 0.23~0.40. The average values of the mechanical properties of fault zone were calculated as follows; unit weight 21.5 kN/㎥, cohesion 48.275 kPa, internal friction angle 29.9°, moduli of deformation 170.9 MPa, and Poisson's ratio 0.3. Whereas unit weights and Poisson's ratios of rocks in fault zone and Class Ⅴ rock mass are almost the same, their cohesion, internal friction angles, and the moduli of deformation show differences as these values in fault zone are 39.1 %, 94.9 %, and 34.4 % respectively of these values in Class Ⅴ rock mass. On reviewing distributions by rock type, it can be seen that the unit weights and Poisson's ratios of rock mass are distributed in similar ranges in fault zone and in Class Ⅴ rock mass regardless of rock types. The cohesion and internal friction angles are distributed in similar ranges in the case of only sedimentary rocks and the values of the moduli of deformation in fault zone are distributed in lower ranges than those in Class Ⅴ rock mass for all rock types.

Keywords: mechanical property, class V by the RMR system, fault zone, weak rock

1. Introduction

Since weak rocks such as fault zone, shear zone, and differential weathering zone remarkably reduce the strength of rock mass, they act as geological risk factors that degrade the stability of constructions during tunneling. In particular, since fault zone becomes a cause of shear strength reduction, decrease of arching effects, the expansion of plastic and stress relaxation zones, the swelling of fault gouge, and decreases in confining pressure of the ground due to groundwater inflows, excessive displacement or collapse may occur during tunneling in these grounds. Therefore, the mechanical properties of weak rocks should be accurately figured out in the design stage to establish excavation and reinforcement methods.

When a tunnel is designed, the mechanical properties of the ground are determined by rock mass rating (RMR) based on the results of in-situ and laboratory tests considering empirical formulas, design cases and references. However, in the planning stage, due to insufficient understanding of weak rocks and temporal and economic restrictions, the mechanical properties for RMR Ⅴ rock mass are unsuitably applied as they are to weak rocks in many cases. In addition, in some cases, collapses occur during tunneling even when the mechanical properties of weak rocks have been cautiously considered and applied to the design. Such cases occur because the heterogeneity of weak rocks was not sufficiently considered in the investigation stage or inappropriate results of in-situ tests were reflected. Furthermore, laboratory tests of weak rocks are hardly conducted because of their difficulties in sampling and specimen shaping. However, studies intended to establish the mechanical properties of fault cataclastic zone and fault gouge have been steadily conducted because of the importance of such studies (Sinha and Singh, 2000; Sulem et al., 2004; Heo et al., 2007; Lee et al., 2007; Chung et al., 2009; Moon et al., 2014).

In the present study, to understand the geotechnical characteristics of weak rocks, the mechanical properties of RMR Ⅴ rock mass and fault zone that are typical weak rocks were collected and analyzed. The mechanical properties used in the analysis are unit weights, cohesion, internal friction angles, the moduli of deformation, and Poisson's ratios determined during tunnel design stage. The mechanical properties of RMR V rock mass were analyzed by collecting data from 64 tunnel design cases and the geotechnical parameters of fault zone were analyzed through various in-situ and laboratory tests and numerical analyses for 21 tunnels.

2. Rock Mass Rating (RMR) system

The rock mass rating (RMR) system was initially developed by Bieniawski (1973) on the basis of his experiences in shallow tunnels in sedimentary rocks. Since then the classification has undergone several significant changes. To apply the RMR, a given site should be divided into a number of geological structural units in such a way that each type of rock mass is represented by a separate geological structural unit (Singh and Goel, 1999). The following six parameters are used to classify a rock mass using the RMR system.

- Uniaxial compressive strength of rock material
- Rock Quality Designation (RQD)
- Spacing of discontinuities
- Condition of discontinuities
- Groundwater conditions
- Orientation of discontinuities

The rock mass rating system is shown in Table 1, giving the ratings for each of the six parameters listed above.

Table 1 Rock mass rating system

A. Classification parameters and ratings									
Parameter			Range of values						
1	Strength of rock material	Point load (MPa)	> 10	4-10	2-4	1-2			
		Uniaxial compressive (MPa)	> 250	100-250	50-100	25-50	5-25	1-5	<1
	Rating		15	12	7	4	2	1	0
2	RQD (%)		90-100	75-90	50-75	25-50	< 25		
	Rating		20	17	13	8	3		
3	Spacing of joint (m)		> 2	0.6-2	0.2-0.6	0.06-0.2	< 0.06		
	Rating		20	15	10	8	5		
4	Condition of discontinuities		Very rough, not continuous, no separation, unweathered wall rock	Slightly rough, separation < 0.1 mm, slightly weathered wall rock	Slightly rough, separation < 1 mm, highly weathered wall rock	Slickenside, gouge < 5 mm, separation 1-5mm, continuous	Slickenside, gouge > 5 mm, separation > 5 mm, continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10 m tunnel length	None	< 10 ℓ	10-25 ℓ	20-125 ℓ	> 125 ℓ		
		Ratio joint water pressure / major stress	0	< 0.1	0.1-0.2	0.2-0.5	> 0.5		
		General conditions	Completely dry	Damp	Moist only	Dripping	Flowing		
	Rating		15	10	7	4	0		

Table 1 (Continued)

B. Rating adjustment for discontinuity orientations (see F)

Strike and dip orientation of joint		Very Favourable	Favourable	Fair	Unfavourable	Very unfavourable
Rating	Tunnels	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

C. Rock mass classes determined from total ratings

Rating	100 ~ 81	80 ~ 61	60 ~ 41	40 ~ 21	20 ~ 0
Class No.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. Meaning of rock mass classes

Class No.	I	II	III	IV	V
Average stand-up time	20 years / 15 m span	1 years / 10 m span	1 week / 5 m span	10 hours / 2.5 m span	30min / 1 m span
Cohesion of rock mass (kPa)	> 400	300-400	200-300	100-200	< 100
Friction angle of rock mass	> 45°	35-45°	25-35°	15-25°	< 15°

E. Guidelines for classifying discontinuity condition

Discontinuity length (persistence) rating	< 1 m 6	1-3 m 4	3-10 m 2	10-20 m 1	> 20 m 0
Seperation (aperture) rating	None 6	< 0.1mm 5	0.1-1mm 4	1-5mm 1	> 5mm 0
Roughness rating	Very rough 6	Rough 5	Slightly Rough 3	Smooth 1	Slicken Slide 0
Infilling (gouge) rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering rating	Fresh 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. The effect of joint strike and dip orientation in tunneling

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip (Dip 45-90°)	Drive with dip (Dip 20-45°)	Dip 45-90°	Dip 20-45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip (Dip 45-90°)	Drive against dip (Dip 20-45°)	Dip 0-20° – Irrespective of strike	
Fair	Unfavourable	Fair	

3. Mechanical properties of RMR Ⅴ rock mass

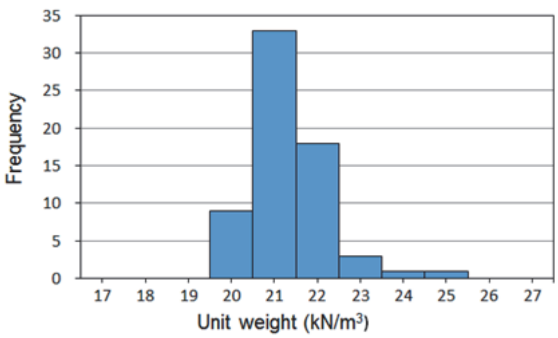
Mechanical properties of RMR Ⅴ rock mass were analyzed using geotechnical parameters applied to 64 tunnel construction in Korea. Fig. 1 (a) shows the unit weights of RMR Ⅴ rock mass as frequencies according to the ranges of the values and Fig. 1 (b) shows unit weights according to rock types. Unit weights are distributed in range of 20.0~24.5 kN/m^3. The interval in which the largest number of unit weights are distributed is 20.5~21.5 kN/m^3 where 33 out of 64 data are distributed and 94 % of the data are distributed in a range of 20.0~22.5 kN/m^3. The average value is 21.3 kN/m^3. The values are the most widely distributed in the case of sedimentary rocks.

Fig. 2 shows the distribution of cohesion of RMR Ⅴ rock mass indicating that the values are distributed in a range of 30~400 kPa. The interval in which the largest number of data is 100~140 kPa where 22 out of 64 are distributed and the average value of cohesion was calculated as 123.4 kPa. According to the results of analysis of cohesion according to rock types, the cohesion of gneiss is distributed in the widest range which is 30~300 kPa while that of granite shows a range of distribution of 30~210 kPa and that of sedimentary rocks shows a range of distribution of 30~200 kPa.

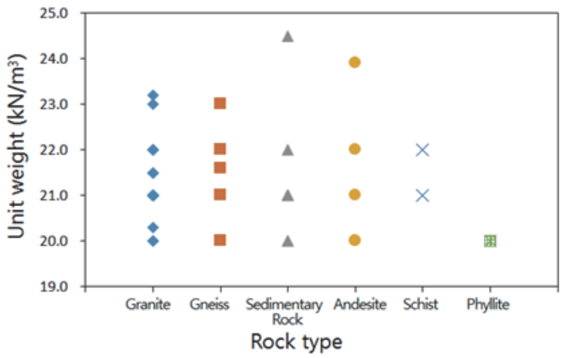
Fig. 3 shows the distribution of internal friction angles of RMR Ⅴ rock mass. The internal friction angles are in a range of 25.0~37.0 ° and approximately 95% of the data are distributed in a range of 29.5~34.5° . The average value of the internal friction angles of RMR Ⅴ rock mass is 31.5° and differences in ranges among rock types are not large.

Fig. 4 shows the distribution of the moduli of deformation of RMR Ⅴ rock mass. The moduli of deformation are quite widely distributed showing a range of 200~1,000 MPa. In particular, wide ranges were shown in granite, gneiss and sedimentary rocks. The values are mainly distributed in a range of 350~550 MPa and high strength rock masses such as granite and gneiss show values in a range of 950~1,000 MPa. The average value of the moduli of deformation of RMR Ⅴ rock mass is 496.4 MPa.

Fig. 5 shows the Poisson's ratios of RMR Ⅴ rock mass indicating that most are intensively distributed in a range of 0.28~0.32 except for only one case that shows a value of 0.33. In addition, the ranges of distribution of Poisson's ratios of different

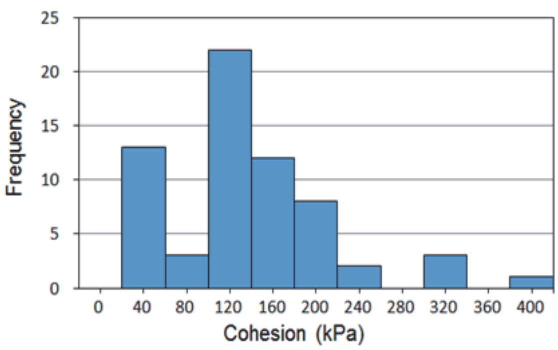


(a) Frequency of unit weights

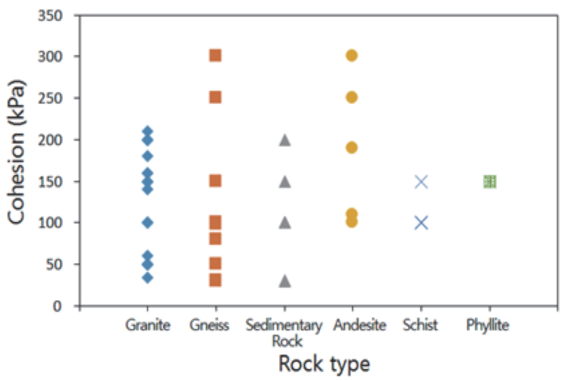


(b) Range of unit weights of rocks

Fig. 1 Frequency and range of unit weights of rock mass class Ⅴ by RMR system

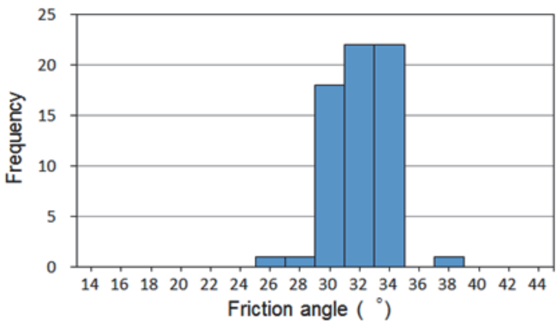


(a) Frequency of cohesion

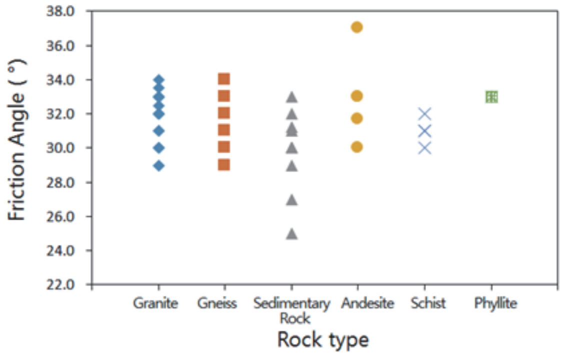


(b) Range of cohesion of rocks

Fig. 2 Frequency and range of cohesion of rock mass class Ⅴ by RMR system

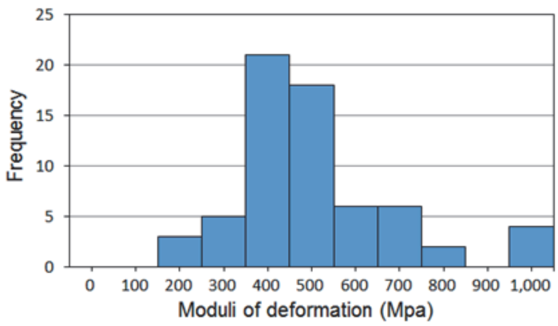


(a) Frequency of friction angles

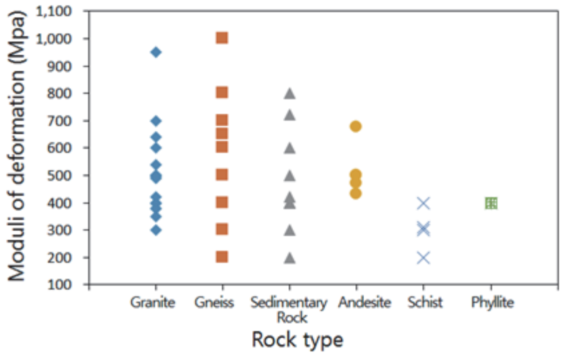


(b) Range of friction angles of rocks

Fig. 3 Frequency and range of friction angles of rock mass class Ⅴ by RMR system

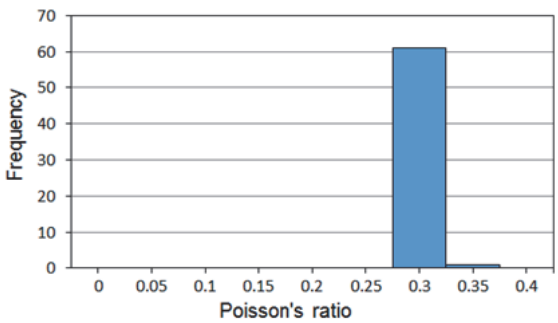


(a) Frequency of moduli of deformation

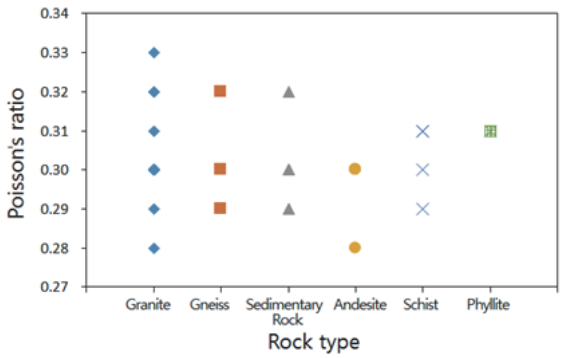


(b) Range of moduli of deformation of rocks

Fig. 4 Frequency and range of moduli of deformation of rock mass class Ⅴ by RMR system



(a) Frequency of Poisson's ratios



(b) Range of Poisson's ratios of rocks

Fig. 5 Frequency and range of Poisson's ratios of rock mass class Ⅴ by RMR system

rock types were shown to be similar to each other.

4. Comparative analysis of the mechanical properties of RMR Ⅴ rock mass and fault zone

3.1 Numerals

Yun et al. (2015) analyzed the mechanical properties of collapsed tunnel due to the effects of fault zone in Korea. The mechanical properties in the previous study and RMR Ⅴ rock mass were comparatively analyzed as Table 2. The ranges of distribution of the values for RMR Ⅴ rock mass are generally narrower compared to fault zone. The reason is considered to be attributable to the methods of determining mechanical properties in the design stage. In general, geological characteristics are not sufficiently reflected when mechanical properties of

Table 2 Range, average and ratio of mechanical properties of fault zone and RMR Ⅴ rock mass

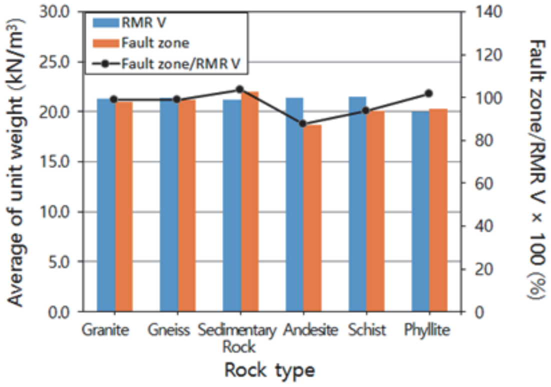
Rock type \ Mechanical property		Unit weight (kN/m³)	Cohesion (kPa)	Friction angle (°)	Moduli of deformation (MPa)	Poisson's ratio
Fault zone	Range	17.3~26.3	0.036~260	14.7~44.1	3.5~800.0	0.23~0.4
	Average	21.5	48.3	29.9	170.9	0.3
RMR Ⅴ	Range	20.0~24.5	30~300	25.0~37.0	200~1,000	0.28~0.33
	Average	21.3	123.4	31.5	496.4	0.3
Ratio of average		1.01	0.39	0.95	0.34	1.00

RMR Ⅴ rock mass are determined in the design stage because diverse data such as in-situ and laboratory test results, design data, and references are comprehensively analyzed and the average values are used. On the other hand, the mechanical properties of fault zones are determined using the test results for samples collected from various fault zones and numerical analytical methods so that the heterogeneity of faults is sufficiently reflected. The average value of unit weights of fault zone is similar to that of RMR Ⅴ rock mass and the average value of Poisson's ratios of fault zone was calculated to be the same as that of RMR Ⅴ rock mass. The average values of cohesion, internal friction angles, and the moduli of deformation of fault zone are shown to be lower by 39.1 %, 94.9 % and 34.4 % respectively compared to those of RMR Ⅴ rock mass.

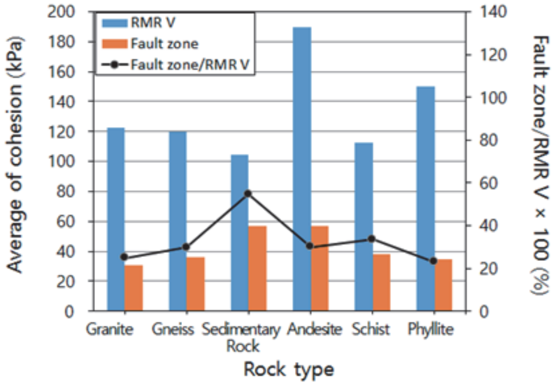
Fig. 6 shows an analysis of the average values of the mechanical properties of fault zone and RMR Ⅴ rock mass by rock type. The bar graphs show the average values of the mechanical properties of fault zone and RMR Ⅴ rock mass by rock type and the linear graphs shows the ratios of the average values of the mechanical properties of fault zone to those of the mechanical properties of RMR Ⅴ rock mass by rock type. According to the results of the analysis, whereas the average unit weights of RMR Ⅴ rock mass are in a range of 20.0~21.5 kN/m³ indicating not much differences among rock types, the average unit weights of fault zone are distributed in a range of 18.7~22.0 kN/m³ which is wider compared to RMR Ⅴ rock mass. In addition, whereas the average unit weights of fault zone are a little lower compared to RMR Ⅴ rock mass amounting to 87.5~98.8 % of those of RMR Ⅴ rock mass in the case of granite, gneiss, andesite and schist, they are higher compared to RMR Ⅴ rock mass in the case of sedimentary rocks and phyllite. When the cohesion and internal friction angles that determine the characteristics of shear strength of fault zones were compared with those of RMR Ⅴ rock mass, those of sedimentary rocks were shown to have the least difference and in the case of internal friction angles, the average values of fault zone were shown to be higher. It shows that since most of collected sedimentary rocks are shale and mudstone which are swelling rocks, clay minerals reduced shear strength. On the other hand, on reviewing the ratios of the average values of the mechanical properties of fault zone to the RMR Ⅴ rock mass by rock type, it can be seen that andesite shows the largest differences in all mechanical properties except for cohesion. However, the reliability of this result is low because the number of data on andesite is not larger than 5. The average moduli of deformation of fault zone shows remarkably lower values amounting to 21.8~83.4 % of those of RMR Ⅴ rock mass. Since the moduli of deformation are importantly used during continuous numerical analyses in the tunnel design stage for stability analysis and the establishment of reinforcement methods, applying the mechanical properties of RMR Ⅴ rock mass to fault zone may cause serious problems to the stability of tunnel constructions. Therefore, when weak rocks are distributed, the mechanical properties of the weak rocks should be accurately analyzed and reflect those on design and excavation work.

5. Conclusions

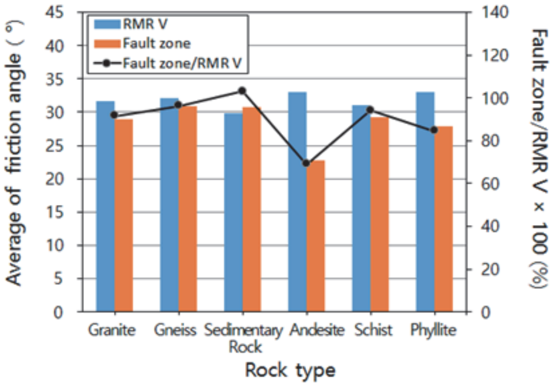
The mechanical properties of weak rocks are remarkably poorer compared to surrounding grounds and not only cause the instability of constructions but also their values are distributed in a quite wide range even within the same site. Although such states may result from site conditions, technicians' skill levels or the reliability of test results, a primary cause is high levels of heterogeneity resulting from different degrees of damage by fault movements. Therefore, to accurately understand the mechanical properties of weak rocks, geometry of fault zone should be accurately analyzed, the area of weak rocks should be subdivided into fault gouge zone, cataclastic zones, etc., and diverse data collected from in-situ and laboratory tests, case analysis and references should be comprehensively reviewed and evaluated.



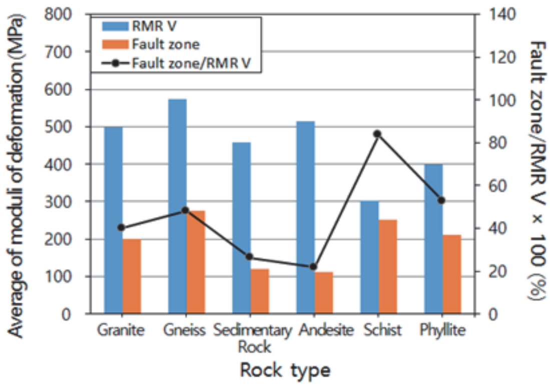
(a) Unit weight



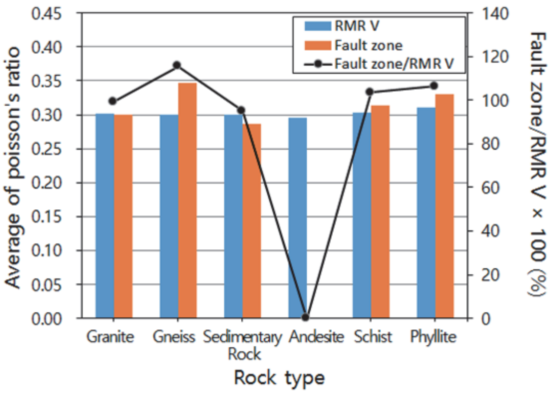
(b) Cohesion



(c) Friction angle



(d) Moduli of deformation



(e) Poisson's ratio

Fig. 6 Average values and ratios of mechanical properties of fault zone and RMR Ⅴ rock mass by rock type

Acknowledgements

This research was supported by a grant (13SCIP-C069074-01) from the Ministry of Land, Infrastructure and Transport of Korean government.

References

Bieniawski, Z.T. (1973): Engineering classification of jointed rock masses, Transactions of South African Institution of Civil Engineers, Vol. 15, No. 12, pp. 335-344.

Chung, H.Y., Kim, Y.G., Park, Y.J. and You, K.H. (2009): A study on analysis for the characteristics of fault zone at mica-schist for reinforcement of large-span tunnel, Tunnel & Unerground Space, Journal of Korean Society for Rock Mechanics, Vol. 19, No. 2, pp. 132-145.

Heo, J.S., Jeong, J.H. and Kim, H.S. (2007): A review on the engineering characteristics and the investigation/testing method for the fault, Korean Geotechnical Society Fall National Conference. Busan. pp. 147-159.

Lee, K.M., Lee, S.H., Seo, Y.S., Kim, C.Y. and Kim, K.S. (2007): Petro-mineralogical and mechanical property of fault material in phyllitic rock tunnel, The Journal of Engineering Geology, Vol. 17, No. 3, pp. 339-350.

Moon, S.W., Yun, H.S., Kim, W.S., Na, J.H., Kim, C.Y. and Seo, Y.S. (2014): Correlation analysis between weight ratio and shear strength of fault materials using multiple regression analysis, The Journal of Engineering Geology, Vol. 24, No. 3, pp. 1-13.

Singh, B. and Goel, R.K. (1999): Rock mass classification, Elsevier Science Ltd., pp. 34-39

Sinha, U.N. and Singh, B. (2000): Testing of rock joints filled with gouge using a triaxial apparatus, International Journal of Rock Mechanics and Mining Sciences, 37, pp. 963-981.

Sulem, J., Vardoulakis, I., Ouffoukh, H., Boulon, M. and Hans, J. (2004): Experimental characterization of the thermo-poro-mechanical properties of the Aegion Fault gouge, C.R. Geoscience, 336, pp.455-466.

Yun, H.S., Moon, S.W., Song G.J. and Seo, Y.S. (2015): Case studies of geotechnical parameters applied on collapsed tunnels in fault zone of Korea, KGS Spring National Conference 2015, pp. 755-758.