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Mechanical Properties of Fault Rocks in Korea

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To understand the mechanical properties of fault rocks, data from 584 in situ and laboratory tests on fault rocks from 33 tunnels were analyzed. The unit weights of the fault rocks range from 17.3 to 28.2 kN/m^3 and the cohesion and friction angles vary from 5 to 260 kPa and 14.7° to 44.0°, respectively. The modulus of deformation and elasticity were generally < 200 MPa. In most cases, the uniaxial compressive strength was < 0.5 MPa, and Poisson's ratios were mainly 0.20-0.35. The mechanical properties of individual rock types were analyzed using box plots, revealing that the cohesion values and friction angles of shale and phyllite have relatively wide inter-quartile ranges and that the modulus of deformation and elasticity of shale have the lowest values of all rock types. In the analysis of mechanical properties by components of fault rocks, the largest values were shown in damage zones of individual rock types.

Key words: mechanical properties, fault rock, tunnel, rock type, fault rock components

Introduction

Fault rocks are a critical geological risk factor that hinder the stability of tunnel, slope, or dam construction and substantially reduce the strength of rock masses. In particular, in tunnels, fault rocks become a factor that expands stress relaxation zones during excavation and thereby cause instabilities in ground stress that may lead to collapse. Tunnel collapses in South Korea have occurred mainly in weak rocks such as fault rocks (KTA, 2010; Yun et al., 2014). Therefore, identifying the existence of fault rocks around tunnels and their mechanical properties in the investigation and design stages is important. However, in many cases, such properties cannot be clearly analyzed due to an insufficient understanding of the fault rock properties. Although fault rocks generally have low strength and are characterized by being of a disaggregated, crumbly, high plasticity, slaking, and rapidly weathering nature (Kanji, 2014), quantitative analysis of these properties is challenging. Quantitative analyses of fault rocks can be made through in situ and laboratory tests when constructions are being designed; however, accurate analyses of these properties are not straightforward. Kanji (2014) explained that weak rocks such as fault rocks have strength levels between those of soils and hard rocks, and that they are too soft to be tested with rock mechanics equipment and too hard to be tested with soil mechanics equipment. In addition, robust test results cannot be obtained from very weak fault rocks because sampling disturbs the collected material. As such, when constructions are designed for stability, the mechanical properties of fault rocks are conservatively determined after analysis of diverse empirical formulae and design case studies. However, this approach may lead to over-reinforcement during construction and increased costs.

Many studies have attempted to quantitatively identify the mechanical properties of fault rocks through experimental approaches and analyses using a variety of methods. For example, Galván (1999) concluded that the upper limit of the strength of weak rocks does not exceed 25 MPa through analysis of many case studies that employed uniaxial compressive strength data. Terzaghi and Peck (1967) showed that the lower limit of uniaxial compressive strength of materials such as rocks (excluding soil) is greater than 0.4 MPa. In addition, Galván (1999) analyzed the correlations between the diverse physical-mechanical properties of weak rocks, including clay, after compiling numerous data published in the past 30 years. Galván (1999) concluded that the dry density and uniaxial compressive strength have a S-

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shaped relationship based on the results of studies conducted by Kanji (1990) and Kanji and Galván (1998). In studies conducted by Nieto (1982) and Kanji and Galván (1998), the relationships between rock water contents and their uniaxial compressive strength were examined for mudstone, Canadian clay-rich rock, and Caiua sandstone samples. Previous studies have also considered the relationship between uniaxial compressive strength and the elastic modulus at 50% of the ultimate strength (E_{50}), and that between the dynamic modulus of elasticity measured in intact rocks by sonic velocity and the static modulus (E_{50}) (Deere, 1968; Kanji and Galván, 1998). Recently, the mechanical properties of fault gouge have also been studied (Ikari et al., 2009; Tesei et al., 2012) to analyze the effects of infillings between joint planes on rock strength (Kulatilake et al., 1995; Sinha and Singh, 2000; Jang et al., 2010; Woo, 2012). The shear strength of fault gouge has also been widely studied (Sulem et al., 2004; Lee et al., 2007; Henderson et al., 2010; Moon et al., 2014; Yun et al., 2015). In addition, studies intended to identify the mechanical properties of fault rocks for the building of constructions such as tunnels and dams have also been conducted (Heo et al., 2007; Chung et al., 2009; Kim et al., 2012). Analysis of these case studies and test data can further improve our understanding of the mechanical properties of fault rocks.

In this study, in situ and laboratory test data obtained on fault rocks were collected and analyzed to identify the mechanical properties of fault rocks in South Korea. Individual tests were conducted during the design and construction stages of 33 tunnels that pass through fault zones. The data used for these analyses include the unit weight, cohesion, the friction angle, the modulus of deformation, the modulus of elasticity, uniaxial compressive strength, and Poisson's ratio. These mechanical properties were analyzed according to rock type and fault rock components, and the results compared with the geotechnical parameters used for design in RMR V rock masses.

Data collection

The mechanical properties of fault rocks were investigated by compiling and analyzing data from 584 design and construction tests from 33 tunnels that pass through faults (Fig. 1a). The data includes measurements of unit weight (n = 111), cohesion (n = 106), friction angle (n = 98), modulus of deformation (n = 125), modulus of elasticity (n = 45), uniaxial compressive strength (n = 41), and Poisson's ratio (n = 58) (Fig. 1b). The most data available was for shale and basement fault rocks consisting of six rock types, including schist, gneiss, phyllite, andesite, and granite (Fig. 1c). The fault rocks were classified into gouge, breccia, cataclasite, and damage zones according to their constituent components (Fig. 1d).

Analysis of mechanical properties

Variations in mechanical properties

Figure 2 shows histograms of the ranges of individual mechanical properties. The unit weights (moist unit weights) were calculated from laboratory tests, in situ gamma-gamma responses, and S-PS logging. The unit weights vary from 17.3 to 28.2 kN/m^3 and are most densely distributed in a range from 22.0 to 23.0 kN/m^3 (Fig. 2a). The cohesion and friction angles were calculated from direct shear tests,

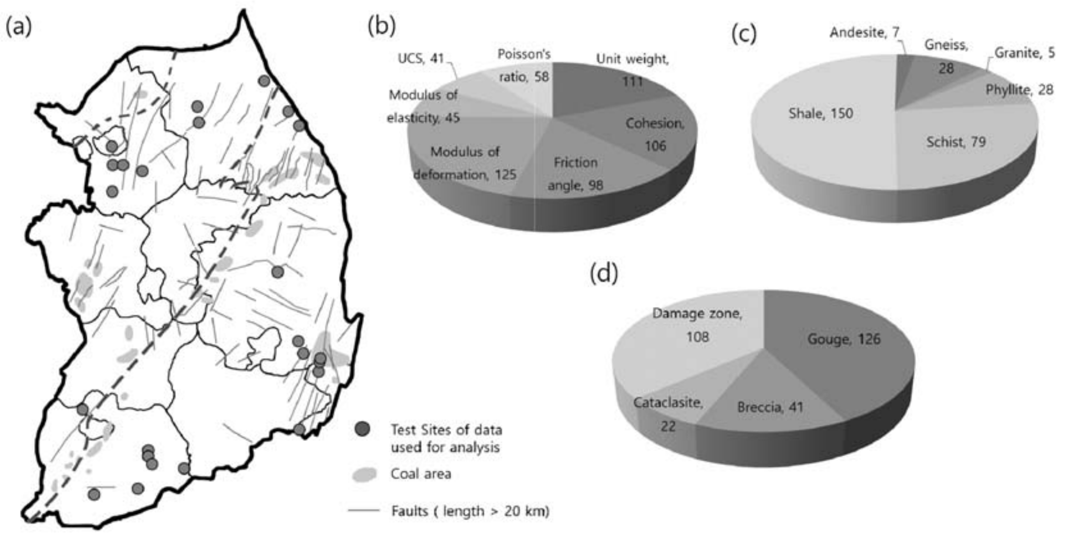

Fig. 1. Test data used for analysis in this study. (a) Test sites superimposed on the fault map published by Chang et al. (2003), (b) mechanical properties, (c) rock types, and (d) fault rock types.

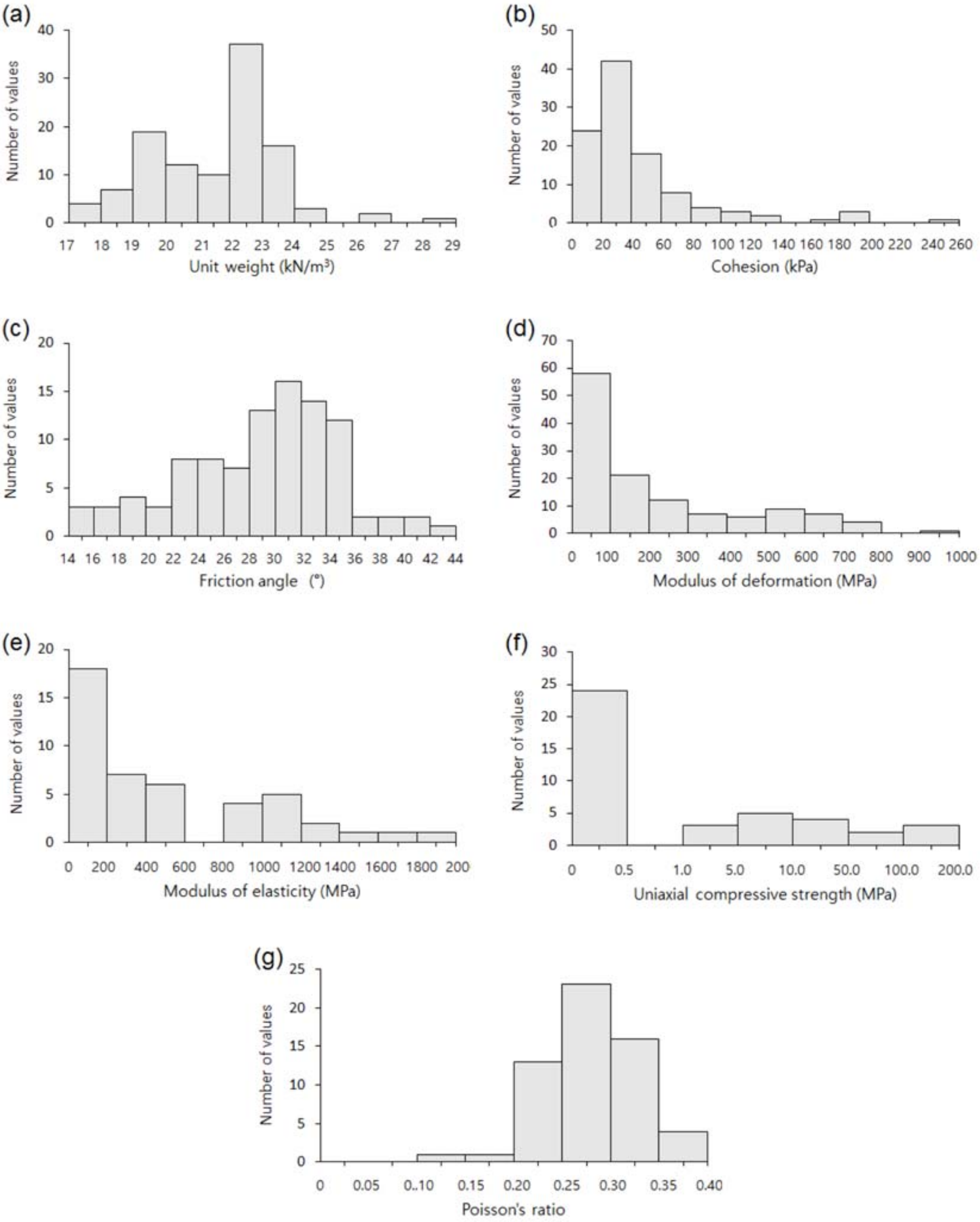

Fig. 2. Histograms of (a) unit weight, (b) cohesion, (c) friction angle, (d) modulus of deformation, (e) modulus of elasticity, (f) uniaxial compressive strength, and (g) Poisson's ratio.

triaxial compression tests, and in situ borehole shear tests. The cohesion values vary from 5 to 260 kPa and are most densely distributed in the range from 20 to 40 kPa. Friction angles vary from 14.7° to 44.0°, but are mainly 28.0° to 36.0° (Fig. 2b and 2c). The modulus of deformation and elasticity were calculated based on in situ pressuremeter tests, and they vary from 3.5 to 953.0 and 5.9 to 1,823.0 MPa, respectively, but both are mostly < 200 MPa (Fig. 2d and 2e). The uniaxial compressive strength and Poisson's ratio were calculated from uniaxial compression tests, point load tests, and pressuremeter tests. The uniaxial compressive strength values have a wide range from 0.01 to 176.70 MPa, but are generally < 0.5 MPa, and Poisson's ratio falls mainly in a range from 0.2 to 0.35 (Fig. 2f and 2g).

Mechanical properties according to rock type

Figure 3 shows the results of analysis of the mechanical properties of individual rock types using box plots. Box

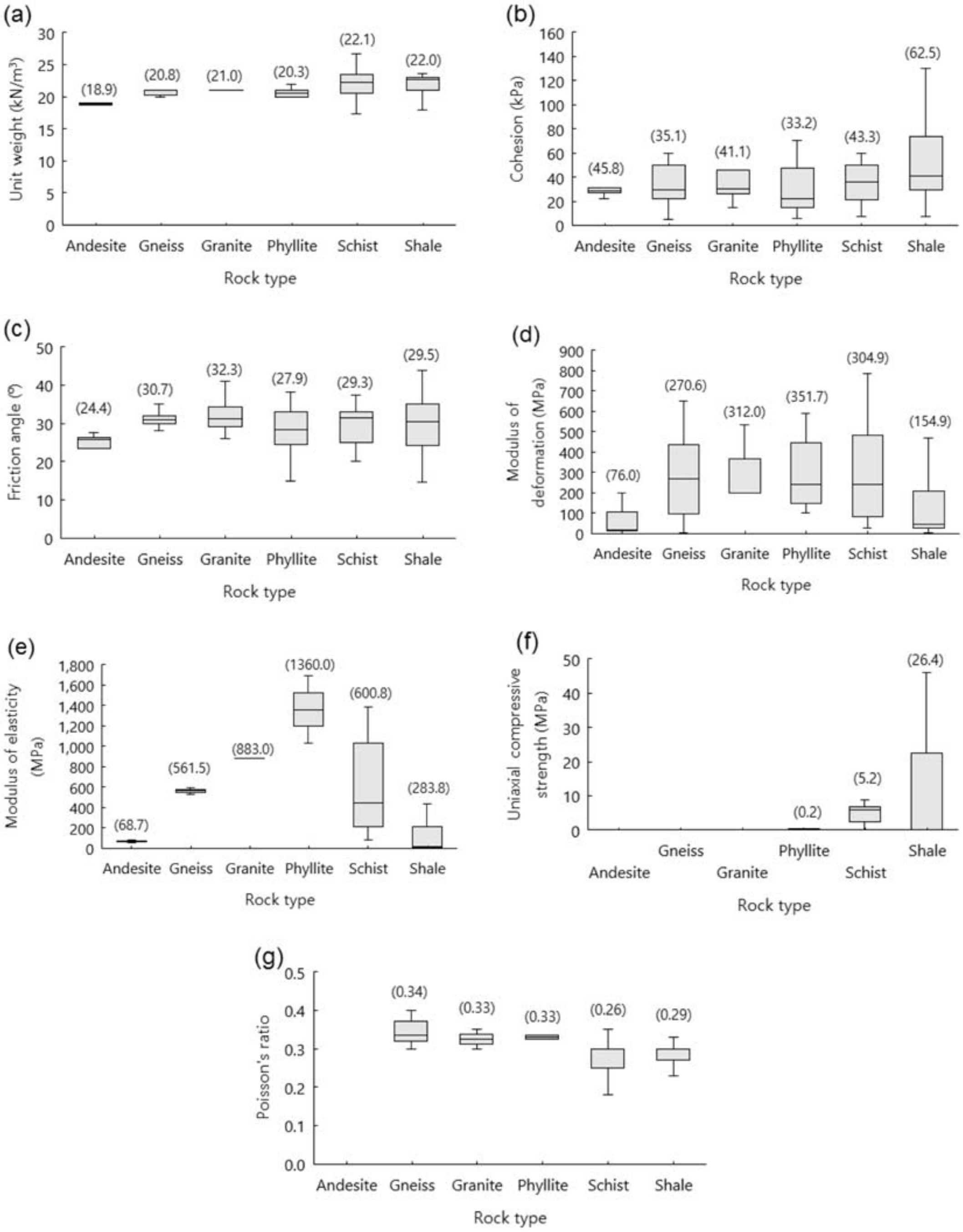

Fig. 3. Box plots of (a) unit weight, (b) cohesion, (c) friction angle, (d) modulus of deformation, (e) modulus of elasticity, (f) uniaxial compressive strength, and (g) Poisson's ratio by rock type. The numbers in parentheses are mean values and the gray boxes are IQRs (inter-quartile ranges).

plots enable easy visualization of data distributions among groups when the amount of data for individual groups is large, by comparing the medians, inter-quartile ranges (IQRs), and whisker ranges of individual groups with each other (Tukey, 1970). In addition, box plots enable identification of outlier data by setting IQRs. In this study, outlier data were removed because the IQRs are not clearly shown when the outlier data are included. Analysis of the unit weights according to rock type showed that the IQR was as large as 20.6-23.5 kN/m^3 in schist (mean value = 22.1 kN/m^3) (Fig. 3a). The mean unit weight was lowest for andesite (18.9 kN/m^3), although the unit weights were similar among the rock types, with a range from 20.3 to 22.1 kN/m^3. The mean value of cohesion was greatest in shale (62.5 kPa) and lowest in phyllite (33.2 kPa). The IQRs were widest in shale (29.5-73.8 kPa) (Fig. 3b). The mean friction angles varied from 24.4° to 32.3° and showed little difference among rock types (Fig. 3c). In addition, given that the cohesion values and friction angles of shale and phyllite have relatively wide IQRs as compared with other rock types, care is necessary when the shear strength properties of shale and phyllite are analyzed. The modulus of deformation and elasticity are parameters related to the deformability of rock masses and rocks, which are important for numerical stability analyses in the tunnel design stage. The modulus of deformation for the fault rocks shows IQRs < 500 MPa in most rock types, and the mean value was lowest in shale (154.9 MPa; Fig. 3d). The modulus of elasticity of shale was calculated to be

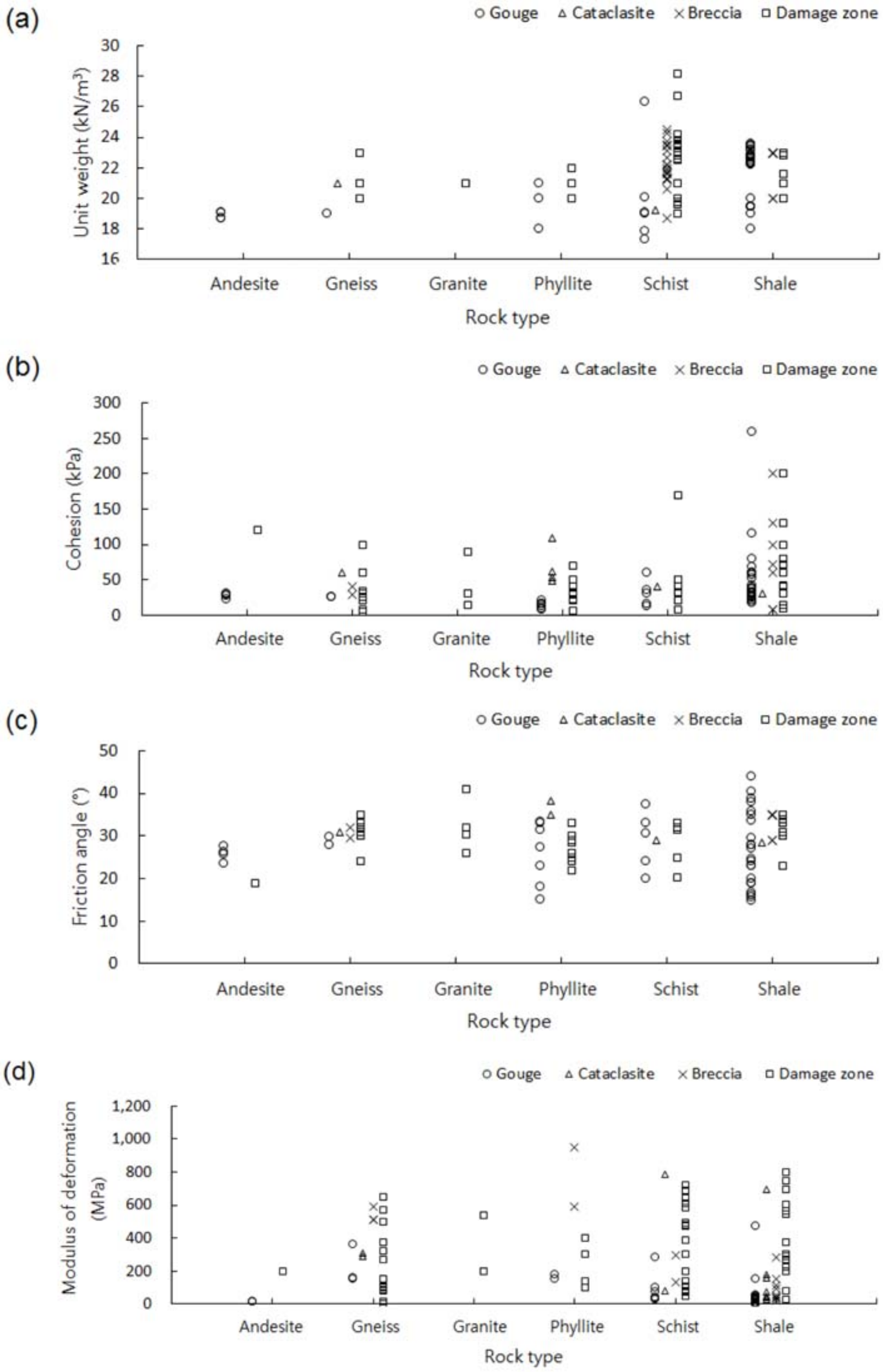

Fig. 4. (a) Unit weight, (b) cohesion, (c) friction angle, (d) modulus of deformation, (e) modulus of elasticity, (f) uniaxial compressive strength, and (g) Poisson's ratios of fault rock components.

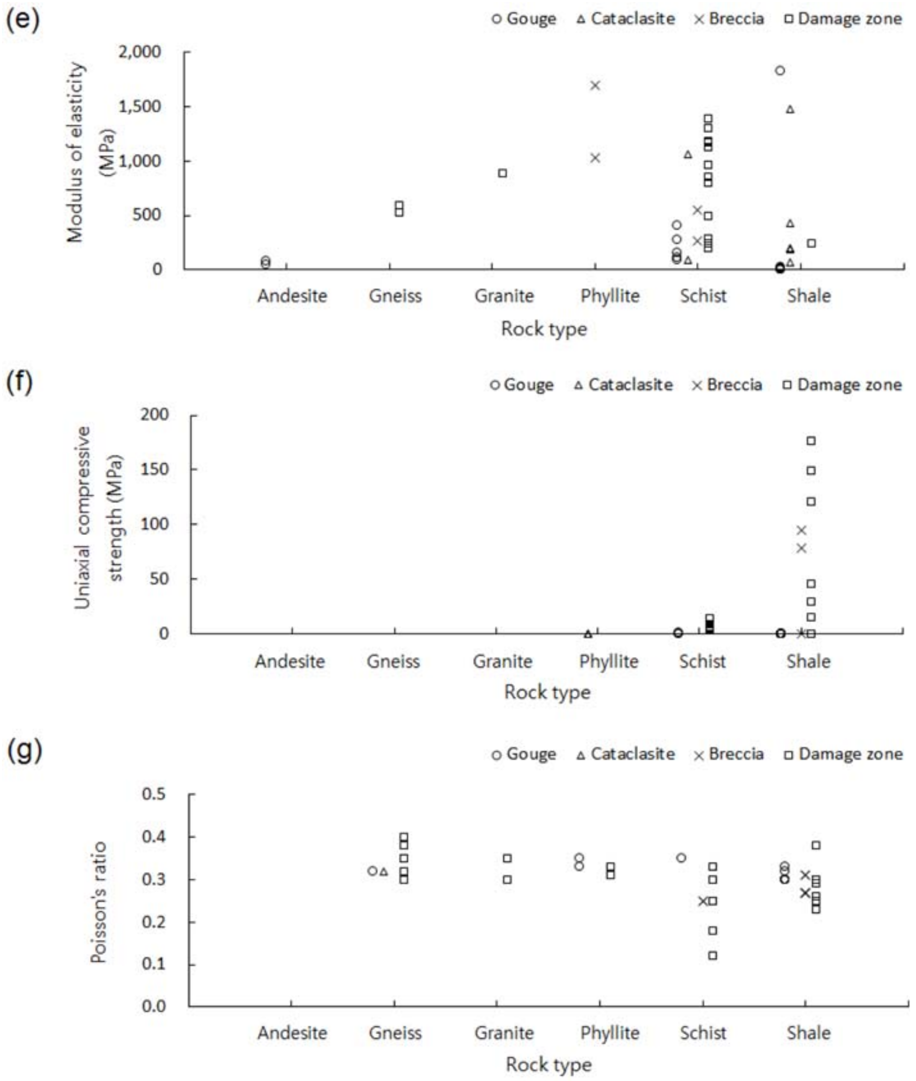

Fig. 4. continued.

283.8 MPa, which is lower than for the other rock types (Fig. 3e). This reflects the high swelling and anisotropy, and low slaking durability of shale due to the presence of clays. The IQRs of Poisson's ratio are smallest in schist (0.25-0.30) and largest in gneiss (0.32-0.37) (Fig. 3f). The mean Poisson's ratio was lowest in schist (0.26) and highest in gneiss (0.34). The uniaxial compressive strength exhibited the widest IQRs and the highest mean value in shale, but relative comparisons were complicated by the limited amount of data available (Fig. 3g).

Mechanical properties according to fault rock components

Fault zones are generally classified into fault cores and damage zones based on their constituent components, and fault cores are subdivided into fault gouge, cataclasite, and breccia (Gudmundsson et al., 2010). Given that the components that constitute fault zones are diverse and range from gouge to rock, their mechanical properties vary. Therefore, the specimens used in the tests were divided into groups based on their components and mechanical properties. Figure 4 shows the mechanical properties according to the fault constituent components and rock types, and Table 1 lists the mean values of these mechanical properties. Unit weights in most rocks were calculated to be higher in damage zones than in other components, but the difference in unit weights among the components was not large in the case of shale (Fig. 4a). Given that shale is composed mainly of fine-grained clay, its gouge and damage zone should only differ in terms of cementation and thus show little difference in unit weights. The cohesion values are also higher in damage zones for most rock types, apart from the values of 108.7 kPa in phyllite cataclasite and 260 kPa in shale gouge (Fig. 4b). The friction angles of phyllite have a higher mean

Table 1. Mean values of mechanical properties by fault rock component for each rock type.

Mechanical properties	Fault rock components	Rock type					
		Andesite	Gneiss	Granite	Phyllite	Schist	Shale
Unit weight (kN/m^3)	Gouge	18.9	19.0	-	18.0	19.9	22.0
	Cataclasite	-	21.0	-	-	19.2	-
	Breccia	-	-	-	-	22.2	22.0
	Damage zone	-	21.3	21.0	21.0	22.8	21.9
Cohesion (kPa)	Gouge	27.3	25.5	-	13.7	30.6	50.1
	Cataclasite	-	60.0	-	67.8	40	31.0
	Breccia	-	34.7	-	-	-	82.3
	Damage zone	120.0	34.6	42.1	33.0	52.93	77.7
Friction angle (°)	Gouge	25.8	29.0	-	25.9	29	27.0
	Cataclasite	-	31.0	-	36.6	29	28.4
	Breccia	-	30.9	-	-	-	33.0
	Damage zone	19.0	31.0	32.3	27.6	29.5	32.2
Modulus of deformation (MPa)	Gouge	14.1	223.4	-	165.0	91.5	42.1
	Cataclasite	-	310.0	-	-	434	173.9
	Breccia	-	537.9	-	772.5	214.2	92.7
	Damage zone	200.0	222.7	312.0	234.7	371.8	401.4
Modulus of elasticity (MPa)	Gouge	68.7	-	-	-	209.1	192.4
	Cataclasite	-	-	-	-	573.3	473.5
	Breccia	-	-	-	-	-	57.8
	Damage zone	-	-	-	-	7.01	67.2
Uniaxial compressive strength (MPa)	Gouge	-	-	-	-	0.54	0.1
	Cataclasite	-	-	-	0.21	-	-
	Breccia	-	-	-	-	-	57.8
	Damage zone	-	-	-	-	7.01	67.2
Poisson's ratio	Gouge	-	0.32	-	0.34	0.35	0.31
	Cataclasite	-	0.32	-	-	-	-
	Breccia	-	-	-	-	0.25	0.28
	Damage zone	-	0.35	0.33	0.32	0.26	0.28

value of 36.6° in cataclasite as compared with damage zones, although this result cannot be regarded as being meaningful due to the limited data (Table 1). The friction angles of schist and shale have the widest ranges in gouge, and the mean values were 29° and 27°, respectively, which are lower than for the other components (Fig. 4c; Table 1). Although the modulus of deformation for phyllite has a higher mean value of 772.5 MPa in breccia as compared with damage zones, most rock types have wider ranges and higher mean values in damage zones (Table 1). A comparison of the modulus of elasticity and uniaxial compressive strength was not possible due to the small amount of data available for these properties.

Comparative analysis of the mechanical properties of RMR V rock masses and fault rocks

The mechanical properties of RMR V rock masses may be used in cases where fault rocks are not recognized during the investigation and design stages. Therefore, in this study, the design geotechnical parameters applied to RMR V rock masses in 88 tunnels were compiled and analyzed along with the mechanical properties of the fault rocks. The mechanical properties used in this analysis were the unit weight, cohesion, friction angle, modulus of deformation, and Poisson's ratio.

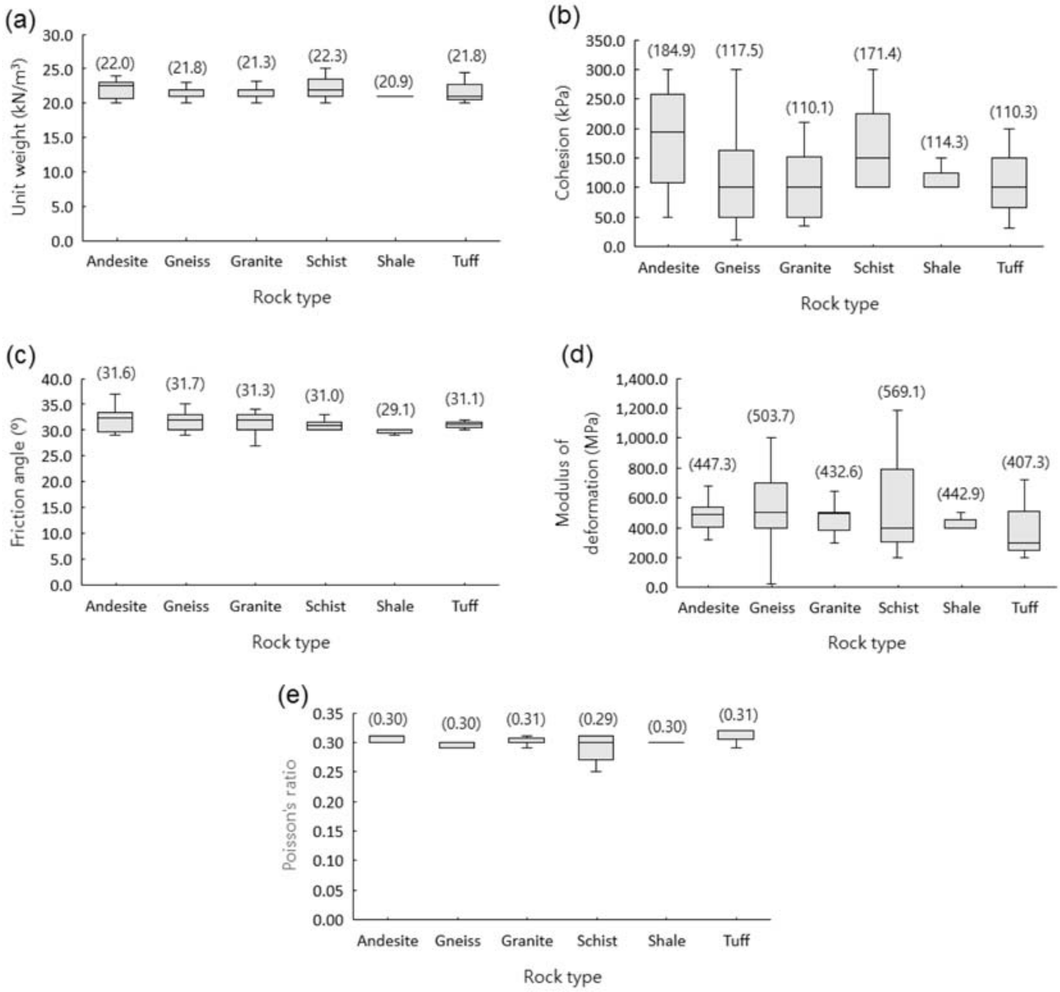

Fig. 5. Box plots of (a) unit weight, (b) cohesion, (c) friction angle, (d) modulus of deformation, and (e) Poisson's ratio by rock type in RMR V rock masses. The numbers in parentheses are mean values and the gray boxes are IQRs (inter-quartile ranges).

Mechanical properties of RMR V rock masses

Figure 5 shows the mechanical properties of RMR V rock masses by rock type. The unit weights of RMR V rock masses show that the IQRs and mean values vary from 20.8 to 23.5 and 20.9 to 22.3 kN/m^3, respectively, and exhibit little difference between rock types (Fig. 5a). The IQRs of cohesion in andesite and schist were calculated to be 107.5-257.5 and 100.0-225.0 kPa, respectively, and the mean values are 184.9 and 117.5 kPa, respectively (Fig. 5b). Rock types other than andesite and schist have similar mean cohesion values that are in the range from 110.1 to 117.5 kPa. The mean friction angle and Poisson's ratio are 29.1^o-31.7^o and 0.29-0.31, respectively, with little difference evident among rock types (Fig. 5c and 5e). The IQRs of the modulus of deformation for andesite, granite, and shale are 402.5-540.0, 385.0-500.0, and 400.0-450.0 MPa, respectively, which are lower than those of gneiss, schist, and tuff. The mean value is highest in schist (569.1 MPa) and lowest in tuff (407.3 MPa) (Fig. 5d).

Results of the comparative analysis

The mechanical properties of fault rocks and RMR V rock masses were compared and analyzed according to rock type, using the mean values (Figs. 3 and 5). The comparison was conducted for andesite, gneiss, granite, schist, and shale. The unit weight of andesite in RMR V rock masses was 22.0 kN/m^3, which is ca. 1.2 times that in fault rocks (18.9 kN/m^3), whereas the unit weights of the other rock types were similar in RMR V rock masses and fault rocks (Fig. 6a). The mean cohesion value of andesite in RMR V rock masses is 184.9 MPa, which is approximately four times larger than in the fault rocks. The mean cohesion value showed the smallest difference between RMR V rock masses and fault rocks for shale (Fig. 6b). Similar to the analysis of unit weight, the friction angle showed differences between RMR V rock masses and fault rocks of a factor of ca. 1.3 in andesite, and little difference for other rock types (Fig. 6c). The mean value of the modulus of deformation for andesite in RMR V rock masses is 447.3

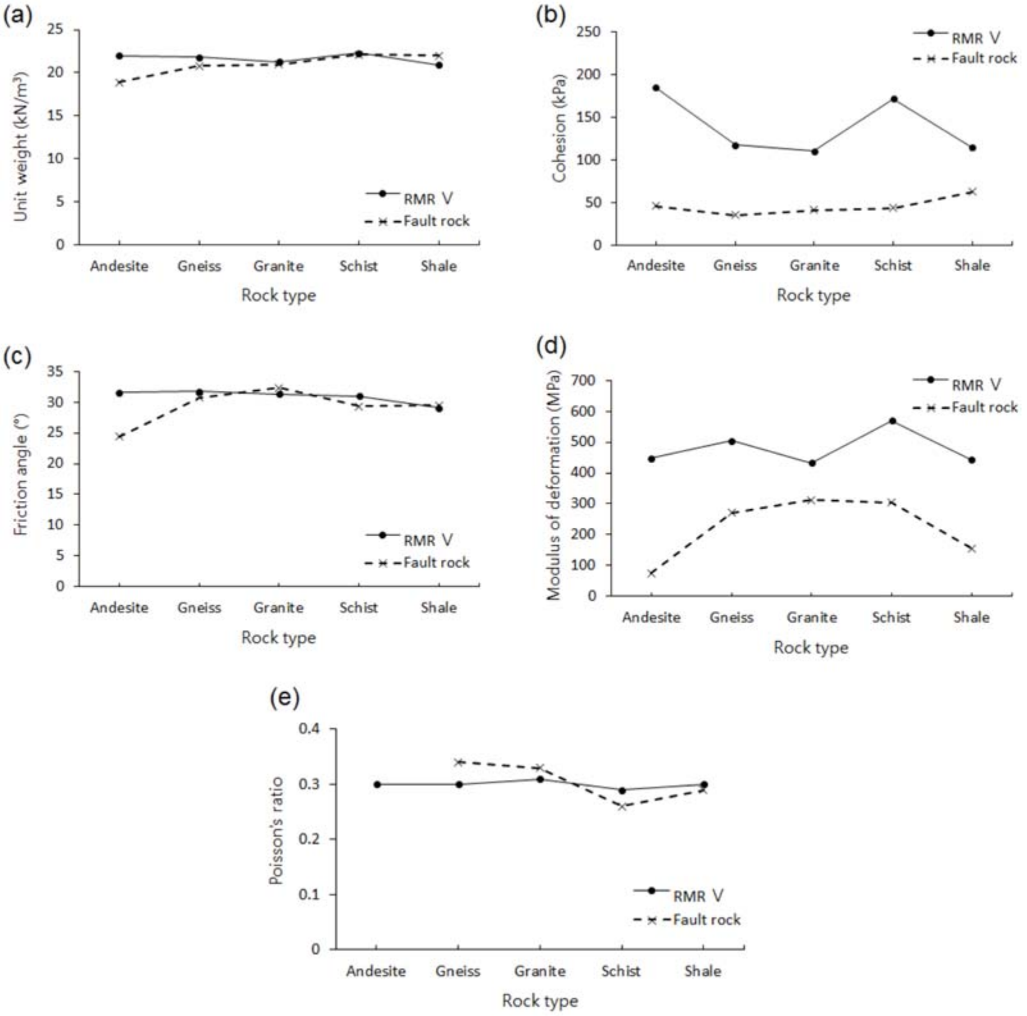

Fig. 6. Results of the comparative analysis of mean values of (a) unit weight, (b) cohesion, (c) friction angle, (d) modulus of deformation, and (e) Poisson's ratio of fault rocks and RMR V rock masses according to rock type.

MPa, which is ca. 5.9 times that of fault rocks (76.0 MPa). The mean values of the modulus of deformation of the other rock types are 1.4-2.9 times larger than in RMR V rock masses as compared with fault rocks (Fig. 6d). Poisson's ratio do not show any significant differences between RMR V rock masses and fault rocks (Fig. 6e).

Conclusions

The mechanical properties of fault rocks cannot be easily investigated and tested, and fault rocks have very low strength that reduces the stability of constructions such as tunnels. Furthermore, mechanical properties vary according to rock occurrence, origin, and formation age, even for a given type. In addition, although the mechanical properties may vary according to the surrounding environment, the skill of engineers, the in situ conditions, and the reliability of test results may also vary with the degree of ground damage by faulting and the constituent material of the fault rocks. Therefore, the type, location, and components of fault rocks should be comprehensively analyzed for quantitative assessments of fault rock properties. In addition, the stability and safety of construction work requires the mechanical properties of fault rocks to be constrained through reliable testing and analysis. The results of this study were obtained through analysis of test results conducted on many fault rocks in South Korea and design data, and can be used during future construction works.

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References

Chang, T. W., Kim, C. S., and Bae, D. S., Characteristics of fracture systems in south Korea, The Journal of Engineering Geology, 13(2), 207-225 (in Korean with English abstract).

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 and Underground Space, Journal of Korean Society for Rock Mechanics, 19(2), 132-145 (in Korean with English abstract).

Deere, D. U., 1968, Geologic considerations, In Stagg K. G., Zienkiewicz, O. (Eds.), Rock mechanics in engineering practice, New York, John Wiley and Sons.

Galván, V. R., 1999, Simulation of the geotechnical properties of arenaceous soft rocks by means of artificial materials, PhD Thesis, So Paulo, Escola Politcnica, Universidade de So Paulo (in Portuguese).

Gudmundsson, A., Simmenes, T. H., Belinda, L., and Philipp, S. L., 2010, Effects of internal structure and local stresses on fracture propagation, deflection, and arrest in fault zones, Journal of Structural Geology, 32(11), 1643-1655.

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, 147-159 (in Korean).

Henderson, I. H. C., Ganerod, G. V., and Braathen, A., 2010, The relationship between particle characteristics and frictional strength in basal fault breccias: Implications for fault-rock evolution and rockslide susceptibility, Tectonophysics, 486(1-4), 132-149.

Ikari, M. J., Saffer, D. M., and Marone, C., 2009, Frictional and hydrologic properties of clay-rich fault gouge, Journal of Geophysical Research, 114, B05409, doi:10.1029/2008JB006089.

Jang, B. A., Kim, T. H., and Jang, H. S., 2010, Characterization of the three dimensional roughness of rock joints and proposal of a modified shear strength criterion, The Journal of Engineering Geology, 20(3), 319-327 (in Korean with English abstract).

Kanji M. A., 1990, Dam foundation on weak and fractured rocks: problems and solutions, In Proceedings of the 3rd South American Congress on Rock Mechanics, Caracas, 235-252 (in Spanish).

Kanji, M. A., 2014, Critical issues in soft rocks, Journal of Rock Mechanics and Geotechnical Engineering, 6, 186-195.

Kanji, M. A. and Galván, V. L., 1998, Correlation of properties of soft rocks, In Proceedings of the 2nd International Symposium on Hard Soils and Soft Rocks, Naples, Rotterdam, A.A. Balkema, 239-244.

Kim, H. J., Lyu, Y. G., Kim, Y. G., and Lim, H. D., 2012, A study on optimization for location and type of dam considering the characteristic of large fault, Tunnel and Underground Space, Journal of Korean Society for Rock Mechanics, 22(4), 227-242 (in Korean with English abstract).

Korean Tunnelling Association (KTA), 2010, Case histories of tunnel collapse, CIR publication, 380p (in Korean).

Kulatilake, P. H. S. W., Shou, G., Huang, T. H., and Morgan, R. M., 1995, New peak shear strength criteria for anisotropic rock joints, International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts, 32(7), 673-697.

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, 17(3), 339-350 (in Korean with English abstract).

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, 24(3), 397-409 (in Korean with English abstract).

Nieto, A., 1982, Geotechnical characterization of soft rock masses, In Proceedings of the 1st South-American Congress on Rock Mechanics, Bogotá, 1-69 (in Spanish).

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, 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, 455-466.

Terzaghi, K. and Peck, R., 1967, Soil mechanics in engineering practice, New York, John Wiley and Sons.

Tesei, T., Collettini, C., Carpenter, B. M., Viti, C., and Marone, C., 2012, Frictional strength and healing behavior of phyllosilicate-rich faults, Journal of Geophysical Research, 117, B09402, doi:10.1029/2012JB009204.

Tukey, J. W., 1970, Exploratory data analysis, Addison-Wesley, preliminary edition.

Woo, I., 2012, Laboratory study of the shear characteristics of fault gouges around Mt. Gumjung, Busan, The Journal of Engineering Geology, 22(1), 113-121 (in Korean with English abstract).

Yun, H. S., Song, G. J., Shin, Y. W., Choi, J. W., Kim, C. Y., and Seo, Y. S., 2014, The analysis on hazard and reinforcement method in case histories of tunnel collapse in Korea, The Korean Society of Engineering Geology Autumn Conference, 157p (in Korean).

Yun, H. S., Moon, S. W., and Seo, Y. S., 2015, Setting of the range for shear strength of fault cores in Gyeongju and Ulsan using regression analysis, Journal of Korean Tunnelling and Underground Space Association, 17(2), 127-140 (in Korean with English abstract).

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