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Engineering Characteristics of Ulleung Island Volcanic rock

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ABSTRACT

Ulleung Island is a South Korean island that is about 120 km east of the Korean Peninsula in the East Sea. Volcanic in origin, the rocky steep-sided island is the top of a large stratovolcano which rises from the seafloor, reaching a maximum elevation of 984 metres at the highest peak. It is known that the island consists primarily of trachyandesite rock. Basaltic agglomerate and trachyagglomerate are partly found along the periphery of the island above sea level. However, the geological conditions and engineering characteristics of the rock formations in the island are sparsely attainable. This study presents the engineering characteristic of igneous rocks in Ulleung Island in comparison with those in Jeju-island, the biggest volcanic island in the Korean Peninsula where the characteristics of rock masses have been better obtained through civil works in the past, by undertaking intensive site investigations for provision of design inputs for a newly bored tunnel. The analysis of mechanical characteristics of the rock has revealed that the volcanic rock in the site is mostly composed of basaltic agglomerate, the uniaxial strength of which ranges from 6.7 to 95.6 MPa, the cohesion does from 4.3 to 11.6 MPa, and the friction angel does from 37.5 to 46.2 degree. The Geological Strength Index, GSI, appears to range from 18 to 83. These results indicate that the average strength of basalt rock in Ulleung Island is lower than that in Jeju Island and Dok Island. Finally this study addresses possible influences of the rock strength characteristics on NATM based tunnel excavation.

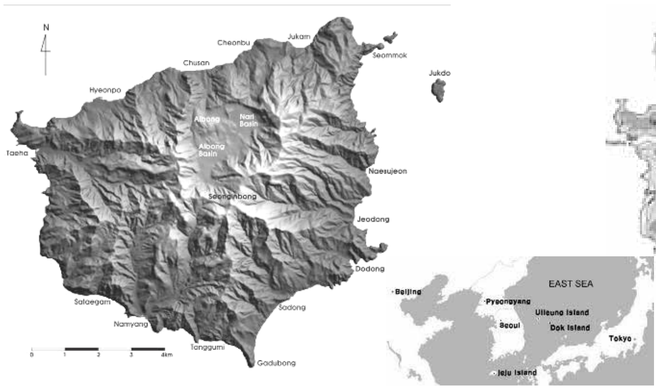
Keywords: Ulleung Island, Volcanic rock, trachyandesite rock, trachyagglomerate

1 INTRODUCTION

Ulleung Island is a massive volcano which rises from the seafloor in the East Sea, having a total height of approximately 3,000m including 1,000 m above sea level, and the major axis of approximately 35 km at the seabed level that is 2,000 m below sea level around Ulleung Island (Figure 1). The island assumes the shape of an irregular pentagon which has the major axis of 12 km in the northeast-southwest direction, the minor axis of approximately 8 km in the northwest-southeast direction, and a circumference of about 53 km. The highest elevation of the island reaches 983.6 m at Seonginbong. (Kim and Lee 2008).

Although the original shape of the volcanoes forming Ulleung Island no longer exists due to tens of thousands years of weathering and erosion, a caldera formed by eruption of lava in the latter stages of volcanic activities, and Albong that means an egg-shaped hill have preserved their original form. Sedimentary basins currently called Nari Basin and Albong Basin have been created inside the caldera after the crater subsided. The outskirts of the basins comprise stiff cliffs which were generated by the caldera subsidence. In addition, the seashore appears to consist of marine cliffs or marine benches with a height of about 10 ~ 70 m except the port area, which indicates rugged terrain of Ulleung Island.

Figure 2 depicts a geological map of Ulleung Island. The exposed portion of the island above sea level is composed partly of basaltic trachyte or of trachybasaltic agglomerate along the perimeter of the island with trachyagglomerate on top of them. However, the majority of the volcanoes below sea level have been hardly explored yet, presumably comprising basaltic rock in spite of absence of subsurface information for those parts. Furthermore, since the engineering characteristics of Ulleung Island volcanics have been rarely identified so far, those of Jeju Island and/or Dok Island that possess the similar geological formations to Ulleung Island have been frequently utilized for practical use. In this study, the engineering characteristics of basaltic rock in Ulleung Island are quantitatively assessed using rock samples taken from a proposed tunnel site in the north-eastern part of the island, and compared with the representative values known for Jeju Island, the biggest volcanic island in Korea where the rock properties had been identified to some extent through several large projects for infrastructures in the past, and Dok Island, a neighboring volcanic island to the east.



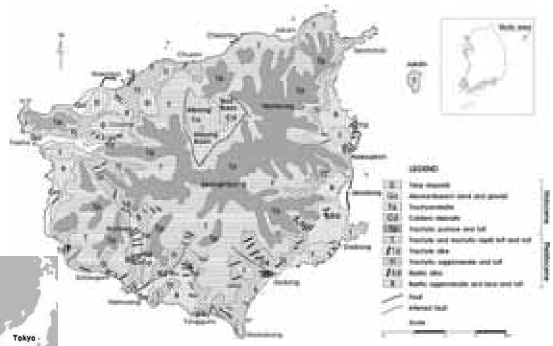


Figure 1. Tomographic map of Ulleung Island (Kim, 2010)

Figure 2. Geological shape of Ulleung Island (Kim, 2010)

2 GEOLOGICAL CHARACTERISTICS OF VOLCANIC ROCK IN ULLUNG ISLAND

2.1 Creation of Ulleung Island volcanic

Figure 3 shows the progress of the creation of Ulleung Island volcanics, and the geological structure. The first stage is where basaltic agglomerate and tuff erupted above sea level, and massive basaltic lava erupted underwater and flew into the sea. After the end of the eruption of basaltic rocks the part of the volcano above sea level was worn away under the influence of weathering and erosion for a long period of time. Then the second stage of volcanic activity started with the eruption of trachy tuff and tuff. At this stage trachytic rock dykes were intruded along the joints in the basaltic rocks having formed during the first stage.

At the third stage trachylava flow erupted resulting in the formation of the current Ulleung Island volcano. At the fourth stage intense explosions triggered off the eruption of trachy-pumice, which resulted in subsidence of the volcanic vent in the center of Ulleung Island so as to create a caldera that later turned to Nari Basin as sediments were deposited on the top. At the fifth stage trachyandesite erupted at the caldera forming Albong that is the central crater, thereafter all the volcanic activities became silent as sedimentation had proceeded within the caldera.

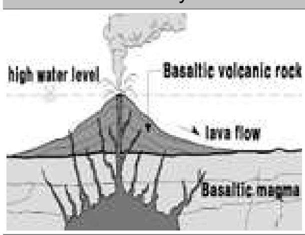
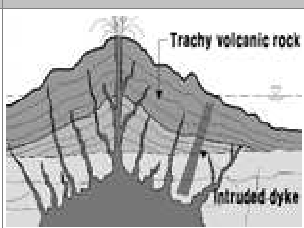
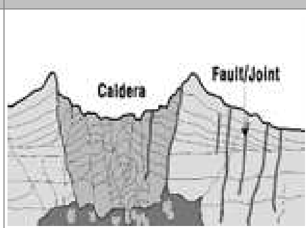
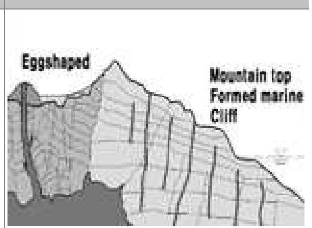
The first stage Before and after Volcanic Activity	The second and third stage Volcanic Activity	The fourth stage Caldera formed	The fifth stage From volcanic activity to Now
			
· Tertiary: basalt eruptions ➔Agglomerate, tuff erupted	·Trachyagglomerate erupted ➔Trachylava erupted	· Trachypumice erupted ➔Crater sinking, Caldera creation	·Trachyandesite erupted ➔Ground uplift, Erosion

Figure 3. Ulleung Island volcanic rocks, the evolution of the geological structure

Figure 4 shows the schematic process for creation of agglomerate and generation of cracks in it. The basalt in Ulleung Island is the oldest and deepest-seated bedrock mostly comprising Basaltic agglomerate so called agglomerate which was considered to be formed by Aa lava. Since Aa lava generally has a higher viscosity than typical basalt and flows slow, solidified rock at the surface is easily broken into pieces and transported by the flow of the inside lava. This solidified rock at the surface of the lava which was broken and distorted is called “clinker” in Jeju Island while it is called “Agglomerate” in Ulleung Island.

The Aa lava is classified into two types addressed as rough-surfaced agglomerate and massive lava. This study is mainly focused on the agglomerate that is found above sea level rather than the massive lava that is mostly distributed below sea level (Figures 5 and 6). Trachyte is volcanic rock created by eruption following to the end of the eruption of the basaltic rock. Therefore, the object of this study is divided into trachytuff, trachyagglomerate and early erupting trachylava (Figures 7 and 8).

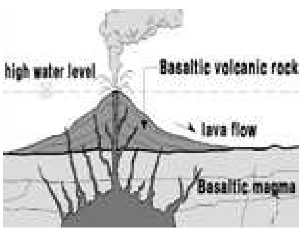
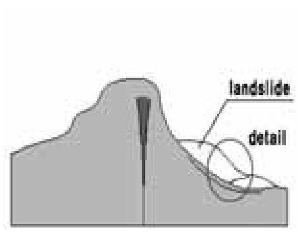
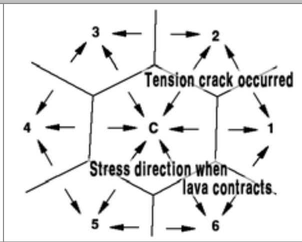
The first stage Basaltic rock erupted	Basaltic agglomerate creation	The second stage Trachy rock erupted	Crack creation
			
· Tertiary: basalt eruptions ➜Former : basaltic lava ➜Later : tuff, Aa Lava	·Basaltic Aa lava flow ➜after surface cooling and broken agglomerate	·Trachyte erupted ➜Former: tuff, agglomerate ➜Later: massive lava	·Lava cooling and contraction ➜ stress occurring ➜ tension crack

Figure 4. Schematic of the process of creating and cracking Agglomerate

Figure 5. Basaltic lava

Figure 6. Basaltic Agglomerate

Figure 7. Trachy dyke

Figure 8. Trachy pumice

3 ENGINEERING CHARACTERISTICS OF VOLCANIC ROCK IN ULLEUNG ISLAND

3.1 Results of rock property tests

Figures 9 and 10 show the measured uniaxial compression strengths and elastic moduli according to rock type, respectively. The volcanic rock in this study was generally classified into basaltic volcanic rock and agglomeratic rock. A comparative analysis has been conducted based on the rock testing results on 19 samples from the two types of volcanic rock. As a result, both of the uniaxial compression strength and elastic modulus of the basaltic rock appeared to be smaller than those of the agglomeratic rock by showing the measured uniaxial compression strength of the basaltic rock 0.1 to 0.5 times smaller than that of the agglomeratic rock. Figure 11 exhibits the uniaxial compression strengths together with the tensile strength according to the type in the Ulleung Island volcanics. Figure 12 shows the cohesions and friction angles simultaneously. In general the uniaxial compression strength, tensile strength and cohesion of the trachyte appeared to be approximately three times larger than those of the basalt, whereas the friction angle the trachyte was observed to be slightly greater than that of the basalt. Figure 13 demonstrates the correlation between the uniaxial compression strengths and point load indexes for the basaltic rock and the trachyte. The slope of the linear squares fitting curve for the basaltic rock and trachyte comes to 12.7 and 32.5 MPa, respectively, which indicates distinctive difference in the correlation between those indexes depending on the type of volcanic rock.

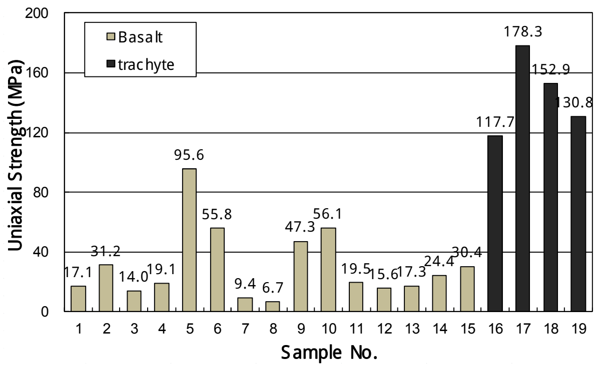


Figure 9. Comparison of uniaxial compression strength according to rock types

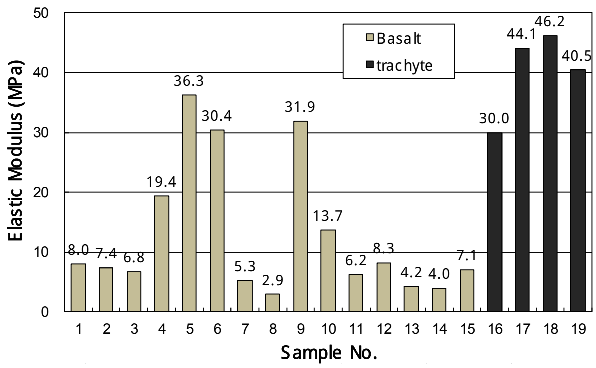


Figure 10. Comparison of elastic modulus according to rock types

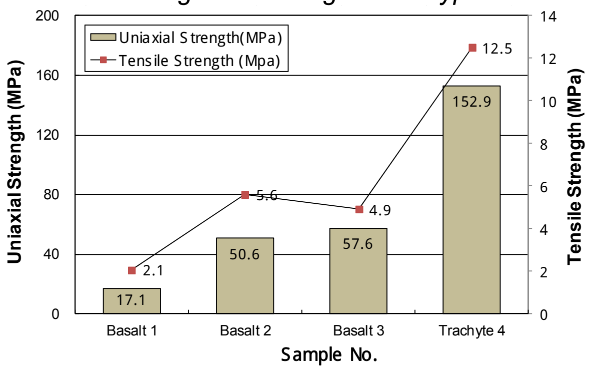


Figure 11. Comparison for uniaxial compression strength and tensile strength

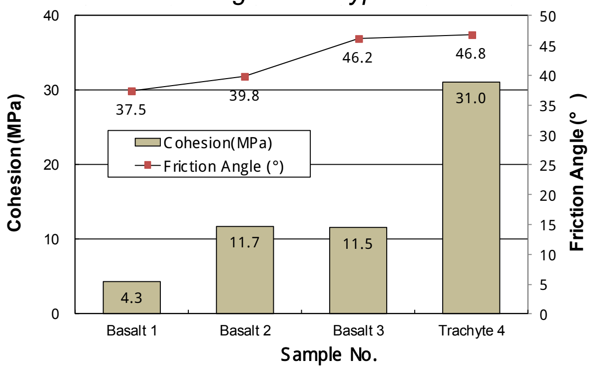
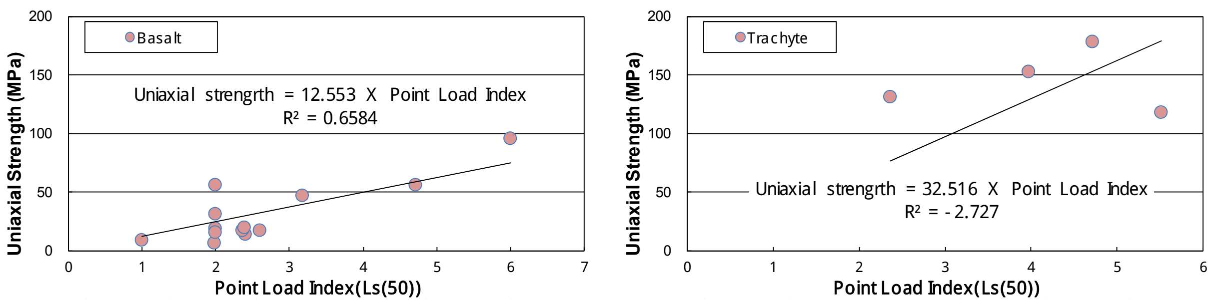


Figure 12. Comparison for friction angle and Cohesion



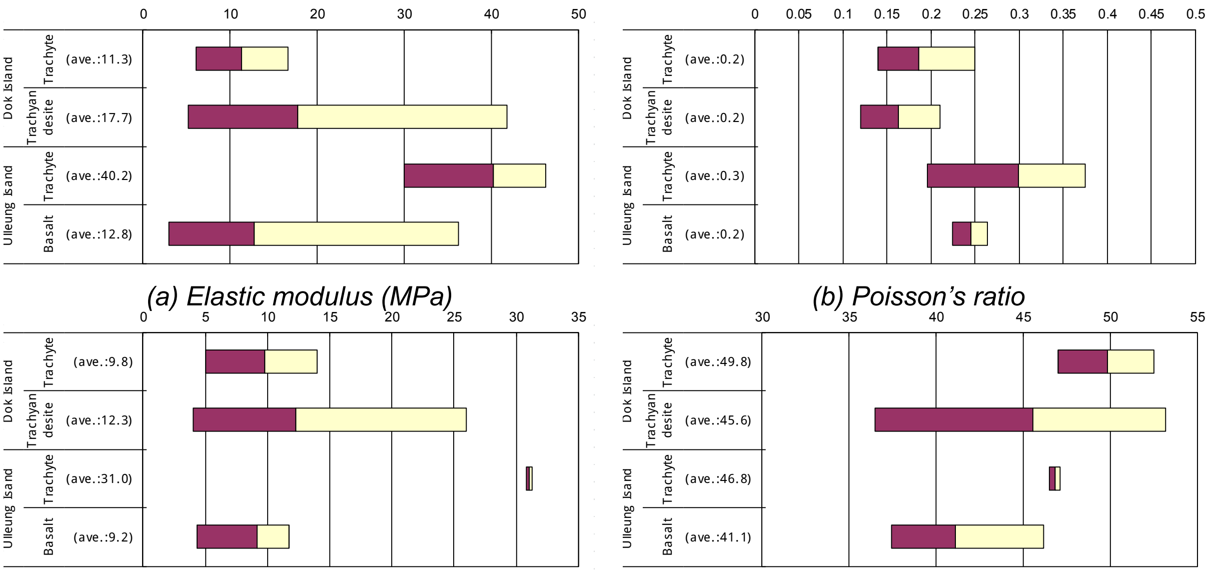
(a) Basaltic rock *(b) Trachyte*

Figure 13. Comparative analysis for uniaxial compression strength and point load index according to rock type

3.2 Comparison of rock properties in Jeju Island and Dok Island

3.2.1 Comparison for physical properties

Figure 14 illustrates the comparison of the physical properties of the volcanic rock in Ulleung Island and Dok Island those are also a volcanic island having the similar origin to Ulleung Island. There is found a reasonable similarity between the elastic moduli and cohesions of the basalts in both Ulleung Island and Dok Island, which were created at the early stages of volcanic activity. However, the elastic modulus and cohesion of the agglomerate in Ulleung Island that originated from the later volcanic activities are obviously greater than those in Dok Island. The Poisson's ratios of the basaltic rock and agglomeratic rock in Ulleung Island come to be both larger than those in Dok Island, while the friction angle of the basaltic rock in Ulleung Island indicates a value slightly less than that of agglomeratic rock in Dok Island. It can be implied from this comparison that some key rock properties such as elastic modulus and cohesion may significantly vary where the trachytic component that was generated by intrusion and eruption at the later stages of volcanic activity is dominant.



(a) Elastic modulus (MPa) *(b) Poisson's ratio*

(c) Cohesion(MPa) *(d) Friction angle (Degree)*

Figure 14. Comparison of rock properties according to regional volcanic rocks

3.2.2 Comparison for strength properties

Figure 15 shows the strength characteristics of the volcanic rock in Ulleung Island in comparison with those of Jeju Island and Dok Island. The basaltic rock in Ulleung Island is showing lower compressive strength than that in the Jeju Island. Meanwhile, the agglomeratic rock in Ulleung Island represents higher compressive strength than that in Jeju and Dok Island. It can be thus inferred that the basaltic rock in Ulleung Island has undergone relatively more weathering than that of Jeju Island, whereas the trachytic rock has been relatively less weathered.

The trachybasalt in Ulleung Island apparently shows stronger tensile strength than that in Jeju Island, whereas the tensile strength of the basaltic rock in Ulleung Island is similar to or less strong than that in Jeju Island. The trachybasalt in Ulleung Island appears to possess greater compressive/tensile strength than the basaltic rock owing to its high content of trachytic component which is considered to be more resistant to weathering. Meanwhile, similarly, in the compressive strength, the agglomeratic rock in Ulleung Island shows higher tensile strength than that in Jeju or Dok Island.

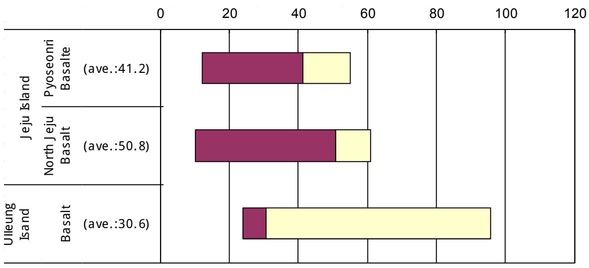
3.2.3 Estimation of GSI index on Ulleung Island volcanic rock

Figure 15 displays the GSI (Geological Strength Index) of the Ulleung Island volcanic rock in comparison with the estimated RMR values. The GSI was analyzed to range from 18 to 83 with an average of 43 (Hoek et al. 2002). Table 1 summarizes a comparison of the strength parameters estimated using the GSI and RMR, which indicates the cohesion from the RMR up to ten times greater than for those from the GSI.

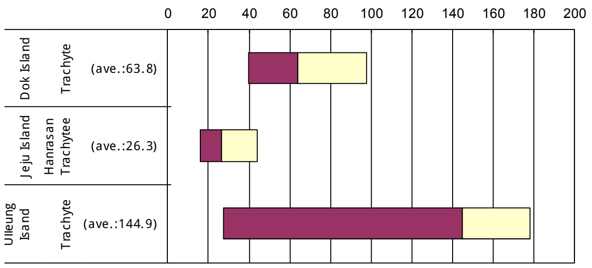
4 CONCLUSION

The engineering characteristics of Ulleung Island volcanics were estimated and compared with those in Jeju and Dok Islands in this study. The results of this study are as follows:

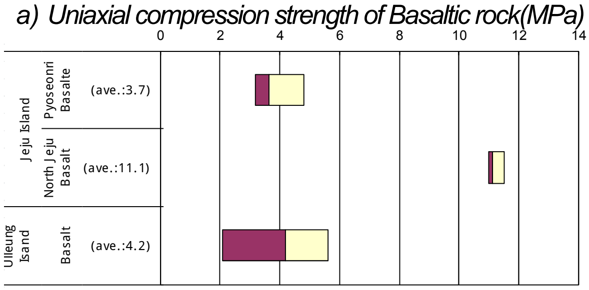
1) The elastic modulus of the basaltic rock appeared to be smaller than those of the agglomeratic rock. The uniaxial compression strength of the basaltic rock came to be 0.1 to 0.5 times as great as those of the agglomeratic rock.
2) The uniaxial compression strength, tensile strength and cohesion of the trachyte appeared to be approximately three times larger than those of the basalt, whereas the friction angle the trachyte was slightly greater than that of the basalt.
3) The elastic modulus and cohesion of the basalt in Ulleung Island appeared to be similar to those in Dok Island. The elastic modulus and cohesion of the agglomerate in Ulleung Island were greater than those in Dok Island. The Poisson's ratio of the basaltic rocks and agglomeratic rock in Ulleung Island were greater than those of the agglomeratic rock in Dok Island. These results imply that rock properties may easily vary in agglomeratic rock where trachytic component is dominant.
4) The trachybasalt in Ulleung Island apparently shows stronger average compressive/tensile strength than that in Jeju Island, whereas the average strength of the basaltic rock in Ulleung Island is similar to or less strong than that in Jeju Island. The trachybasalt in Ulleung Island appears to possess greater compressive/tensile strength than the basaltic rock owing to its high content of trachytic component which is considered to be more resistant to weathering.
5) The GSI of the volcanic rock in Ulleung Island was analyzed to range from 18 to 83 with an average of 43. A remarkably good correlation between the GSI and RMR values was found.



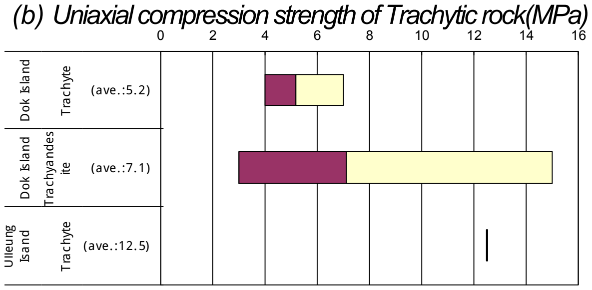
a) Uniaxial compression strength of Basaltic rock(MPa)



(b) Uniaxial compression strength of Trachytic rock(MPa)



(c)Tensile strength of Basaltic rock(MPa)



(d) Tensile strength of trachytic rock(MPa)

Figure 14. Comparison for regional strength characteristic

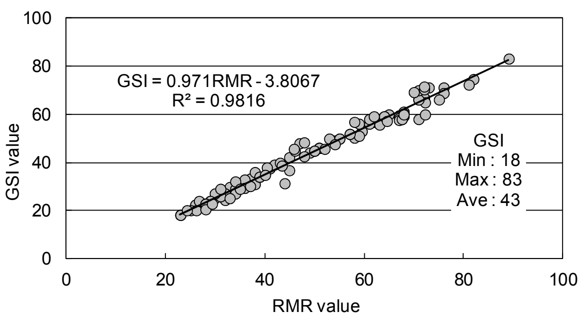


Figure 15. Correlation between GSI and RMR

Table 1: Comparison for Strength Index

Class	Strength index from GSI		Strength index from RMR	
	Cohesion (MPa)	Friction angle (°)	Cohesion (MPa)	Friction angle (°)
1	0.31	47.05	3.60	47.50
2	0.26	45.57	3.00	43.50
3	0.20	41,76	0.83	40.80
4	0.17	39.32	0.45	35.90
5	0.16	38.27	0.07	34.30

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