공학석사 학위논문

# Evaluation of Strength Characteristics and Weathering Grade on a Long Term Weathered Volcanic Rock

## 장기 풍화에 의한 화산암의 강도특성 평가 및 풍화등급 결정에 관한 연구

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이 논문을 공학석사 학위논문으로 제출함

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위 원 ______________________ (인)

# Abstract


## Evaluation of Strength Characteristics and Weathering Grade on a Long Term Weathered Volcanic Rock



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Recently increasing the road construction in according to development of national economy, high cutting slope is frequently constructed in order to get good road line. Rock slope is cut and exposed simultaneously at air pollution, it happens the reduction of strength while proceeding weathering.

Even if we have many studies about weathering of granite and sedimentary rock, we don't have many materials of the study about weathering on volcanic rock.

Therefore in this paper, when we plan the rock slope at volcanic rock, performing the weathering acceleration experiment, we tried to predict the change of rock parameter quantitatively on a long term weathering. we figured out the weathering minerals at volcanic rock presently through chemical sensitivity analysis , tried to suggest the quantitative weathering grade calculating the chemical index of weathering and chemical index of alteration. And we performed slaking durability experiment in order to figure out the durability of rock before-and-after weathering.

We performed the experiment connected physical weathering index such as absorption, elastic wave velocity, coefficient of permeability, uniaxial compressive strength, joint surface shear test and tried to predict the change of the strength and permeability of rock quantitatively before-and after weathering.

We observed the change of rock surface before-and-after weathering through the stereo microscope and scanning electron microscope analysis. The rock parameters from weathering acceleration experiment at volcanic rock are prepared the basic materials to be reasonable design and construction considering the weathering when we plan the real civil structures.

**Keywords : volcanic rock, long term weathering, index of weathering, weathering acceleration experiment, weathering grade**

**Student Number: 2009-23161**

# Contents

# Contents of Figures

# Contents of Tables

# Chapter 1 Introduction

## 1.1 Background

As the construction of roads and railways has been actively conducted for the transport for distribution and tourism with the development of national economy and industrialization, the civil engineering structures such as long tunnels, long bridges and large slopes have been increasing for geometric improvement. In particular, recently in the southern coast, the establishment of roads connecting the land to an island, and an island to another island is actively carried out for the construction of national industrial and tourism complexes.

Large slope is planned inevitably for the establishment of the road, and as the bedrock is located in the shallow depth from the ground surface in Korea, the rock slope accounts for relatively higher proportion among the entire slopes compared to other countries. In general, the planning of the rock slope and the evaluation of the stability of such a slope in the design are performed with the strength parameters obtained at the time of cutting based on the drilling investigation. However, since the cut slope must be maintained and managed semi-permanently, it is considered that the evaluation in consideration of the decrease in the strength parameters caused by the rock weathering due to the long term climatic process is necessary. Terzaghi (1950) suggested that the cause of weathering includes processes of drying and wetting, and freeze-thawe.

The annual precipitation in Korea ranges from 1,200 mm to 1,400 mm, which is seasonally concentrated between June and September, and the collapse of cut slopes occurs mostly during this period. Subsequently, rainfall is considered to have a great impact on the stability of rock slopes. In addition, since there are four distinct seasons in Korea, repeated processes of freezing in winter and thawing in spring cause volume changes, which may lower the stability of rock slopes. Furthermore, as the occurrence of acid rain is increasing due to the rapid growth of industry and the increasing demand for vehicles, the accelerated weathering of rocks due to the acid rain may additionally lower the stability of rock slopes.

Hyeongsik Jeong et al. (1997) evaluated the degree of weathering according to rock types and argued that strength characteristics were lowered according to the degree of weathering. Younghwee Lee et al. (2000) conducted a study on the lowering of engineering characteristics of sedimentary rocks. Likewise substantial studies on rocks with respect to weathering have been carried out by many scholars. However, they were limited on the characteristics of rocks. Accordingly, the study on the stability of the actual rock slope against the long term weathering is rare, and subsequently it is necessary to conduct a study quantitatively evaluating the stability of the slope by elucidating the weathering characteristics by elements of the weathering process that is the cause of the collapse of the slope.

<Table 1.1> Studies on weathering of granites and sediment rocks

| year | Title of study | relative organ or journals |
|---|---|---|
| 2011 | Evaluation of weathering characteristics of sand stone and andesite by freeze-thaw experiment | Tunnel and underground space |
| 2009 | Change of physical characteristics of granites by weathering | Korea arithmetic academy journal |
| 2009 | Materials change and micro-fissure revealation by freeze-thaw of cretaceous period mudstone, Haman county of Kyungsangnamdo | Tunnel and underground space |
| 2007 | Comparison of chemical index of alteration and weathering grade of granites | Korea Geotechnical society/ spring meeting |
| 2004 | Change of geological characteristics by freeze-thaw of cretaceous period shale in Hoengseong county, Kangwondo | Korea Geological Society journals |
| 2004 | Comparison between chemical index of alteration and weathering grade at granites distribution areas | Korea ground water soil environment society |
| 2003 | Weathering of granite weathering rock and estimation of parameters | Doctor of thesis degree DanKook University |
| 2000 | Study on the characteristics of weathering of granites | Doctor of thesis degree KangWon University |

## 1.2 Aims of research and the methods

This study aims to propose an evaluation method of the stability considering the long term weathering characteristics for the area where the rock slope was created during the construction of the bridge connecting Jido and Imjado in Sinan-gun, Jeollanam-do. In most of island regions in Korea, volcanic rocks constitute the major type of rocks, which used to be magma that had been rising to the ground surface due to the volcanic activity and solidified on the surface or at the shallow subsurface. Representative island regions, Jejudo and Ulleungdo, have volcanic rocks such as basalt and trachyte as their bedrock. The bedrock of Jido and Imjado, the target region for this study, is an irregularly distributed mixture of acidic volcanic rocks (tuff, tuff breccia, beschtauile). Since it is expected that volcanic rocks are relatively vulnerable to weathering and their strength is lowered rapidly compared to other types of rocks, the study on the stability against weathering of the rock slope created in the region of volcanic rocks is urgently needed.

In addition, it is expected that in Korea where the climatic and weather characteristics are such that there are four distinct seasons, seasonal winds, and rainfalls concentrated in a certain period, weathering and erosion of the cut rock slope will progress rapidly. Moreover, the penetration of rain is facilitated through the joint crevice, which will result in the collapse of the slope. However, the research on the impact of two important factors on the stability of the slope, which are the penetration characteristics through discontinuous faces within the rock according to the rainfall characteristics and the degree of weathering due to the repeated drying and wetting process at the slope, is yet extremely rare.

Seongsu Kim and Hyeongdong Park (1999) suggested that it is necessary to confirm the impact of particular factors on weathering in their study on the weathering of rocks, and since various factors operate in a complex manner in weathering in the actual natural environment, the generation of an artificial environment in which weathering factors can be controlled is needed. They also suggested that the time scale of natural weathering is too great to be studied and subsequently the acceleration of weathering is absolutely required. They further argued that the most important aspect in such an artificial weathering experiment is to find the relationship between the experimental and actual settings, and that between experimental and natural weathering phenomena.

Accordingly, various weathering reduction experiments including the analysis of the chemical and mechanical sensitivity to weathering, absorption rates before and after weathering, the uniaxial compression experiment, the permeability experiment, the measurement of elastic wave velocity, the joint plane shear experiment and the electron microscopic observation were performed for the volcanic rock region in Sinan-gun, Jeollanam-do, and the reduction in the strength and the permeability characteristics of the rock slope due to the long term weathering were evaluated to identify quantitatively the reduction rate of the rock material properties before and after weathering. Therefore, this thesis eventually aims to evaluate the stability of the rock slope in the volcanic rock region so that an effective and reasonable construction method for protection and reinforcement can be proposed for planning of the rock slope in such a volcanic rock region that is vulnerable to weathering.

As for the methods, the target area was selected, and the geotechnical characteristics of the bedrock were analyzed. Next, samples were collected from the target area and the analysis for weathering minerals were carried out by x-ray to estimate the current degree of weathering. The analysis of the weathering sensitivity and the weathering reduction experiments such as the measurement of absorption rates, the uniaxial compression experiment and the measurement of elastic wave were performed to determine the weathering index and grade. These all lead to the observation of the change in the ground material properties between before and after weathering, and that in the surface of volcanic rocks with the progress of weathering, which will be utilized as evaluation elements for the stability of the rock slope.

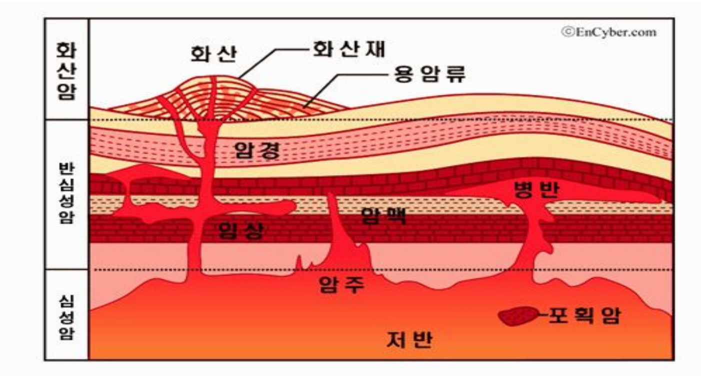
Since the weathering of rocks progresses from the surface of the cut rock, it is important to start the surface protective construction on the rock vulnerable and sensitive to weathering as soon as it is cut. Therefore, herein based on this study, reasonable data are suggested for the stability test considering the weathering process at the time of planning of the slope in the region of volcanic rocks in the future.

# Chapter 2. Theoretical Backgrounds

## 2.1 Geotechnical characteristics of volcanic rocks

When magma comes up to the ground surface or shallow subsurface, and is cooled to solidify, it becomes a volcanic rock, which is also termed an effusive rock. Since magma is cooled and solidifies rapidly at the surface or shallow subsurface, most of volcanic rocks are crystalline or hyaline with very fine particles. As magma already starts to crystallize before reaching the ground surface and subsequently volcanic rocks contain large crystals, these are contained in the ground mass of the fine textured soil that solidifies later. The large crystal contained therein is called a phenocryst, and such a texture is called a porphyritic texture. The magma erupted on the surface contain substantial amount of volatile components, which increases the viscosity and helps the formation of large crystals. Even after a portion of magma solidifies, the remaining magma is still flowing and the solidified incrustation is destroyed. Consequently, a breccia containing irregularly shaped rock blocks or fragments is formed, which is termed an autobrecciated lava.

Since the properties, chemical and mineral compositions of magma are very diverse, a wide variety of volcanic rocks are generated. As mineral particles constituting volcanic rocks are often so fine textured and hyaline that it is difficult to identify types of minerals, the classification method by chemical composition is frequently used. The CIPW Norm calculation method estimates the mineral composition out of the value of the chemical analysis, and the minerals constituting the standard set are termed normative minerals.




<Figure 2.1> Process of becoming Volcanic rock

<Figure 2.1> is a diagram that classifies volcanic rocks according to the correlation of the contents of silicone dioxide ($SiO_2$) and sodium oxide + potassium oxide ($Na_2O$ + $K_2O$). Volcanic rocks are largely classified into alkaline series and non-alkaline series. Non-alkaline series is sub-classified into the high alumina series and tholeiitic series. Thus, volcanic rocks can be classified into three main rock series.

The distribution of these is closely related to tectonic environment. The most abundant type of volcanic rocks in each group is basalt, which accounts for more than 90% of the entire volcanic rocks. Although volcanic rocks are generally divided into basalt, andesite and rhyolite according to chemical and mineral compositions, the distinction between them is not clear. While many scholars intended to classify them based on the average composition of plagioclase, it is the most important to classify them into acidic rocks, intermediate rocks and basic rocks according to the content of silicone dioxide. If classifying them by the mineral composition, a triangular diagram with graphite-alkali feldspar-plagioclase is used, but usually volcanic rocks are amorphous, which makes the mode analysis of mineral composition very difficult. Trachytic rock belongs to the alkaline series, which normally does not contain quartz but orthoclase or anorthoclase among alkali feldspar, or feldspathoids instead of feldspar.

Quaternary volcanic rocks distributed in the Korean peninsula belong to the alkaline series. Basalt and rhyolite are distributed in Baekdusan Mountain, basalt around Giljoo-Myoengcheon rift zone and Chugaryeong rift valley, trachytic rocks in Ulleungdo, basalt and trachytic basalt in Jejudo. Acidic volcanic rocks are distributed in this study′s target area, Jido and Imjado in Sinan-gun, Jeollanam-do, which are composed of tuff, tuff breccia and beschtauile.

## 2.2 Weathering characteristics of rocks

### 2.2.1 Introduction

The surface environment of the earth consists of water, oxygen, carbon dioxide and so on at low temperature and pressure, and if rocks that have been in deep underground are exposed to the surface, they are facing such totally different environment. In such a case, minerals that compose these rocks are to recompose them to a more stable form, and this phenomenon is weathering.

Weathering of rocks occurs by physical degradation, chemical decomposition and biological process. First of all, weathering process depends on the presence of discontinuous faces that provide weathering factors. Accordingly, the initial impact of weathering appears through the discontinuous face and continues to the interior of rock block until the entire block interfaced with the discontinuous face is affected.

The form and rate of weathering are highly diverse depending on climatic conditions. In the highly humid region, chemical and biological processes are generally more important. The rate of weathering in such regions is determined by temperature, humidity, organic material and the undulation of geographical features. At high temperature, weathering occurs more rapidly.

With the increase of temperature by 10 °C, the rate of chemical process increases more than two folds. In addition, as the humidity in surface soil becomes higher, silicate and aluminum silicate are more easily degraded and dissolved. When organic material is dissolved in the penetrating solution, carbon dioxide is generated. Therefore, if more organic material is distributed in the soil, weathering is more facilitated. In order for chemical weathering to be facilitated on the surface layer of rocks, rocks should not move, or rock fragments must be removed to an extent that they will not interfere with the change from alkaline to acidic condition and the removal of soluble materials. If the undulation of the geographical features is substantial, the tendency of physical weathering becomes greater, and eventually the rate of washing down the slope has a higher impact on weathering than that of chemical weathering.

The rate of the progress of weathering depends not only on the activation of weathering elements but also on the durability of relevant rocks. This is determined by the mineral composition, texture, the porosity of rocks, and in addition the occurrence of discontinuous face within rocks.

The intrinsic stability of minerals is affected by the environment in which the minerals have been formed. For instance, minerals crystallized in magma at high temperature and pressure appear in ultrabasic or basic igneous rocks such as peridotite, basalt and gabbro. Thus, these rocks (ultrbasic/basic igneous rocks) are less resistant to weathering than acidic igneous rocks such as plagioclase, muscovite (white mica) and quartz. In particular, muscovite or quartz can withstand severe weathering and even can resist more than a full erosion cycle.

In general, coarse textured rocks are weathered faster than fine textured rocks in the case of rocks with similar mineral composition. The degree of binding between mineral particles is a particularly important structural element, and if rocks are bound to each other more strongly, the resistance to weathering is also stronger. Larger pores between bound particles will allow easier freezing as well as chemical processes.

### 2.2.2 Mechanical Weathering

Mechanical or physical weathering occurs actively in the climate areas that have a wide daily temperature range. The temperature range does not need to be large but may be wide enough to enable freeze-thaw process.

Since the freezing sensitivity of rocks is related to porosity, the size of pores and the moisture content play a very important role. The freezing of pore water results in the increase in volume and subsequently the pressure within pores. This is intensified due to the movement of pore water that is located apart from the growth boundary of ice. Once the ice forms, the pressure exerted by ice increases drastically with the fall of temperature. At –22 °C, the pressure of the ice is approximately 220 MPa (Winkler, 1973). Normally, coarse textured rocks are more resistant to freezing that fine textured rocks. A material that is potentially harmful to the freeze-thaw process might also be included. The development of efflorescence immediately under the rock surface causes the exfoliation with the loss of supporting force of the rock surface. It decrease as the ratio of micropores in all pores is increasing. The pressure exerted by crystallization process in the micropores is substantially high. For instance, 100 MPa is generated in gypsum (CaSO4·nH2O) and 200 MPa in anhydrite (NaCl), which is sufficient to fracture pores.

The fracture within rocks can occur by thermal expansion of salts present in pores. In the case of halite, the volume increases by 0.5% when the temperature changes from 0 °C to 60 °C, which can play a role in the corrosion of rocks to a certain degree. In particular, in the urban environment, the main cause of the corrosion of rocks is the crystallization of salts inside the pores. The impact of the crystallization can be seen through the stability test against the crystallization of sulfides.

Physical process originates from the stress change at the surface layer close to the ground. If stress increases and exceeds the strength of rocks, the rocks will collapse. Changes in the main stress conditions occur by the following processes.

The pressure increases by 1 atm every 4 meter underground from the ground surface. Therefore, if rocks created at the high pressure rise, stress is reduced at the surface and subsequently, they will be placed under very little pressure and expanded, leading to substantial cracks and fractures.

When water freezes, its volume increases by 9%. Accordingly, if water freezes in a sealed place and transforms to an ice at –1 °C, it will exert the pressure of 100 kg/cm2 to its surroundings. However, since the strength of the ice is not normally high at the discontinuous face of rocks, most of the ice inflated due to the volume increase will be pushed out of the gaps, releasing the pressure. Thus, the pressure generated by the frozen water in the open gap of rocks is significantly different from the theoretical value in the sealed space but the repeated freeze-thaw cycle transforms rocks to fine textured particles, which allows weathering to progress.

Atmospheric carbon dioxide dissolved in rainwater will become a weak acid, carbonic acid (H2CO3). A substantial amount of so formed carbonic acid penetrates into soil and goes underground. While it flows through the soil layer, it dissolves minerals mainly contained in the soil and penetrates into the discontinuous face of the bedrock. In a dry season, substantial amount of water distributed near the ground surface evaporates. Likewise, water present in discontinuous faces also evaporates and subsequently a large amount of crystals form in gaps. In other words, materials dissolved in water crystallize as water evaporates off. Accordingly, if such materials are contained in small separative faces between rocks or minerals, crystals that grow therein tend to act similarly to the freezing water, and exert the pressure to surrounding rocks, making fine textured particles.

Most of plants grow rooted in soil and the gaps in the bedrock underneath plants can be paths for the growth of roots. Therefore, as the roots of plants are grwoing and extending, the gap is more widened and segments are eventually separated from the bedrock.

### 2.2.3 Chemical and biological weathering

Chemical weathering is represented as the decomposition of rock minerals or the dissolution of rocks. The decomposition of minerals occurs mainly via oxidation, hydration and hydrolysis, and the dissolution of rocks occurs under the influence of acidic or basic aqueous solution. Chemical weathering weakens the rock texture or worsens the structural defects, leading to the collapse of rocks. When the decomposition occurs within a rock, the altered rock will have a higher volume than before the alteration, and thereby stress is generated. If such expansion occurs near the surface of a rock, the surface will be detached from the parent rock just as skin peels.

While the alteration of rocks occur slowly in a dry state, its rate is accelerated in the presence of moisture. This occurs since moisture can be a cause of weathering itself and contains materials that may react with composition minerals of rocks. Some important materials among them are nascent oxygen, carbon dioxide, organic acids and nitric acid.

Nascent oxygen is a medium that alters every rock containing materials (especially, iron and sulfur) that are easily oxidized. The oxidation rate becomes substantially higher in the presence of water. Water itself reacts with rocks to form hydrates. However, the major role of water is a catalysis. Carbonic acid is generated when carbon dioxide dissolves in water, and its pH is approximately 5.7.

Rocks that have pores with larger diameter than this average value are less affected by the freezing process since water escapes from the growth boundary of the ice. The connection states between pores and space, and pores and pores are also important factors. In particular, the magnitude of stress generated by saturation and freezing depends on the pore structure. While fine textured rocks with 5% absorbed water are generally very sensitive to the damage caused by freezing, those with less than 1% absorbed water has a high resistance to freezing. Repeated process of freeze-thaw creates new cracks and joints, or expands existing pores. As such processes are progressing, rock fragments are gradually separated from the parent rocks.

The physical impacts of weathering are significant in the desert region where the expansion and contraction of rocks are actively occurring due to the large daily temperature range. Since the thermal conductivity of rocks is low, the impact of such physical weathering starts at the surface of rocks. If the expansion and contraction are repeated at the surface of rocks, stress is generated and eventually the fracture occurs therefrom. Such a phenomenon that fragments are separated from the parent rock is called the exfoliation, whose occurrence concentrates on the edge, and subsequently the rock is gradually rounding out. Furthermore, different minerals have different thermal expansion coefficients and thus, the degree of expansion for each mineral is different. Accordingly, stress is generated at the interface of minerals in a rock composed of diverse minerals, and the disintegration of granular phase occurs.

Chemical factors of weathering are much stronger than physical process, and in severe cases, components, properties and textures become completely different from those of the original rock. Every rock is slightly soluble even in pure water, and the collapsing power of the natural water becomes significantly larger in the presence of dissolved oxygen and carbon dioxide, and corrosive compounds. Various processes such as hydration, hydrolysis, oxidation, reduction, carbonation and chelation operate in a complex manner in chemical weathering.

## 2.3 Weathering index and grade of rocks

While the classification of the rock weathering is made in general based on the geological, external and mechanical characteristics, recently the research has been carried out to subdivide the weathering grade by quantitatively evaluating the degree of rock weathering. It is normal to use the weathering index for the quantitative evaluation of weathering of rocks, and the weathering indices that many researchers have suggested to date can be divided mainly into two. One is the physical index that uses lithologic features and the other is the chemical index that applies to the chemical weathering.

The weathering index measures the ratio of a component that is readily removed and the one that is relatively stable during the progress of weathering. Si, Mg, Ca and Na are leaching out while Al and Ti are concentrated as residues in the system. On the other hand, K and Fe display more complicated behaviour when weathering progresses.

Indices that show the degree of chemical weathering using the change of major composition elements have been proposed, and CIA, CIW, PI, SAR, V, Si-Ti index and MWPI are such chemical indices proposed by respective researcher.

· CIA (Chemical index of alteration): This is the most widely used index, which displays the degree of chemical weathering by reflecting the ratio of primary and secondary minerals and a higher number indicates the weathering that has progressed more. While in other indices, particular criteria for a single rock or mineral are not established, certain values for rocks or minerals are determined in CIA and thus it is easy to identify the degree of weathering by the correlation analysis with other indices. Since CIA has low discrimination in carbonate rocks with a high content of CaO in the case of the sedimentary rock, it is necessary to supplement this with other indices or interpret the CIA value by giving 20% or more weight.

· CIW (Chemical Index of Weathering): This is an index that exclude the K2O content from CIA, and a higher number indicates more advanced weathering.

· PI (Weathering direction or product index): Major changes in chemical weathering are the reduction of $SiO_2$ and fluid elements, and the increase of moisture ($H_2O$), which are indicated in this index.

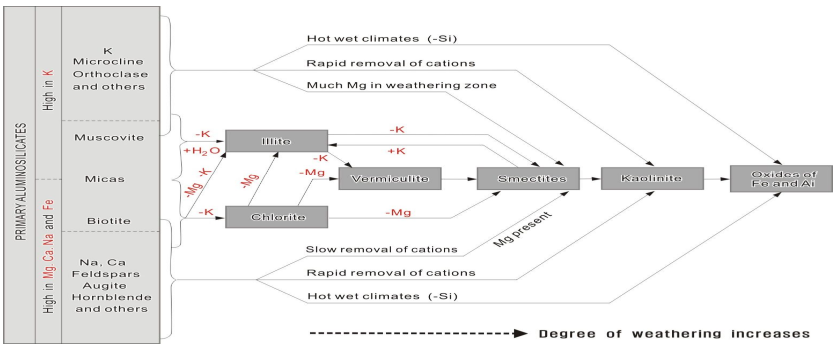
· MWPI (Modified weathering potential index): This is a modified form of PI.

<Table 2.1> shows previously proposed equations of the weathering indices, and the range of the weathering index for fresh and weathered rocks.

<Table 2.1> Summary of weathering indices (modified from Price, 2003)

| Index | Formula | fresh value | weathered value | Ideal trend of index up-profile |
|---|---|---|---|---|
| CIA | [Al2O3/ (Al2O3+CaO+Na2O+K2O)]*100 | ≤50 | 100 | positive |
| CIW (ACN) | [Al2O3/ (Al2O3+CaO+Na2O)]*100 | ≤50 | 100 | positive |
| PIA | [(Al2O3-K2O)/ (Al2O3+CaO-Na2O-K2O)]*100 | ≤50 | 100 | positive |
| WP (WIP) | [(2Na2O/0.35)+ (MgO/0.9)+ (2K2O/0.25)+ (CaO/0.7)]*100 | >100 | 0 | negative |
| SAR (R) | SiO2/Al2O3 | >10 | 0 | negative |
| V | (Al2O3+K2O)/ (MgO+CaO+Na2O) | <1 | Infinite | positive |
| Si-Ti index (STI) | [(SiO2/TiO2)/ ( (SiO2/Al2O3)+ (SiO2/TiO2))]*100 | >90 | 0 | negative |

As the weathering progresses, clay minerals form secondarily and these accelerate the weathering. In particular, the diagnosis of the formation of swelling minerals among clay minerals provides the data that predict the stability of artifacts over the progress of weathering. Many indices that show the degree of chemical weathering using the change of major composition elements in igneous rocks due to weathering have been proposed. Elements in rocks and minerals leach by the chemical weathering, and the amount and rate of leaching are different depending on types of elements. Accordingly, the measurement of the ratio between such chemical species can be an indication of the degree of weathering. Clay minerals are created by the weathering alteration of rock-forming minerals, and such secondarily formed clay minerals accelerate the weathering. <Figure 2.2> models the minerals that can be created from crystalline minerals depending on conditions as the weathering progresses, and illustrates the secondary minerals and final products that will form upon weathering.




<Figure 2.2> Diagram of becoming altered minerals through Weathering(modified from Mason,1966)

Physical weathering index includes elastic wave velocity, void ratio, density and absorption rate, and these evaluate the degree of weathering relatively broadly. For engineering weathering index, the point load test and the strength index using Schmidt hammer are usually used. Hamrol (1961) proposed the absorption rate as the weathering index of rocks by utilizing the characteristics that porosity increases with the progress of weathering, which would increase the saturated water content and decrease the dry density.

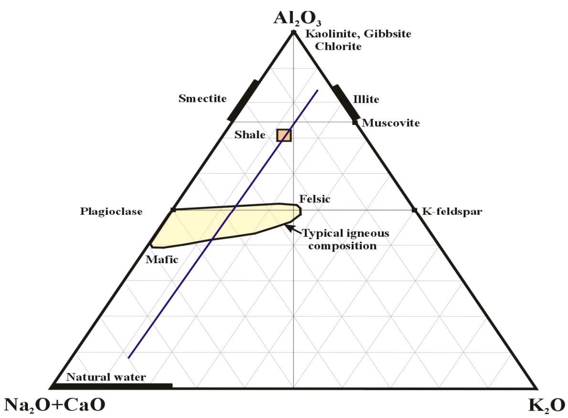
Chemical index of alteration indicates the degree of chemical weathering by applying the ratio of primary and secondary minerals, and the index ranges from 50 to 100. This has a positive correlation with most of other weathering indices.

<Table 2.2> shows the values of chemical index of alteration according to types of rocks and minerals. This study described the characteristics according to types of rocks using chemical index of alteration, which are illustrated in <Figure 2.3>. However, the chemical index of alteration that normally shows higher values for more advanced weathering gives low values for rock with the high CaO content irrespective of the degree of weathering as the ratio of CaO becomes higher. Therefore in this case, CIA is not related to the actual progress of weathering. The representative case of such is sedimentary rocks, and since it is difficult to use CIA in the case of

rocks with the high calcium content such as limestone, it is considered to be necessary to use other weathering indices or apply a weighted value.

<Table 2.2> Chemical index of alteration by rock types and minerals (modified from Nesbitt and Young, 1982, De Jayawardena, U. S. and Izawa, E., 1994)

| Index | rock type | Range of CIA |
|---|---|---|
| feldspar | unaltered albite | 50 |
| | unaltered anorthite | 50 |
| | unaltered K-feldspar | 50 |
| rocks | fresh basalt | 30-45 |
| | fresh granite | 45-55 |
| | fresh granodiorite | 45-55 |
| | shale | 70-75 |
| clay minerals | muscovite | 75 |
| | smectite | 75-87 |
| | kaoline, chlorite | 100 |
| | illite | 75-85 |




<Figure 2.3> Mimetic diagram of chemical index of alteration(modified from Nesbitt and Young, 1982)

It is possible to determine the weathering grade by rock types and apply to the engineering classification of rocks using aforementioned various weathering indices. Irfan and Dearman (1978) suggested the quantitative weathering index of igneous rocks from the results of the absorption rate, density, point load and uniaxial compression tests of rocks. They also reported in the same study that the absorption rate was a useful index that distinguishes the weathering of rocks, and had a good correlation with mechanical characteristics such as uniaxial compression strength and point load strength.

Gupta and Rao (2001) presented 5 or 6 weathering grades for 13 types of rocks using elastic wave velocity, uniaxial compression and tensile strengths, and lithological characteristics such as specific gravity, dry density, wet density, absorption rate and void ratio. In addition, they suggested that although it was not always possible to evaluate weathering grades of all types of rocks reasonably well with the chemical weathering index, the weathering potential index and the ignition loss could be useful as weathering indices for almost all types of rocks.

Sueoka (1988) classified the degree of weathering by 7 levels according to CWI. He proposed a CWI that could divide igneous rocks in Japan into the 7 weathering grades, and suggested that it could describe the entire weathering processes of igneous rocks and weathered residual soil, and was consistent well with the engineering purpose.

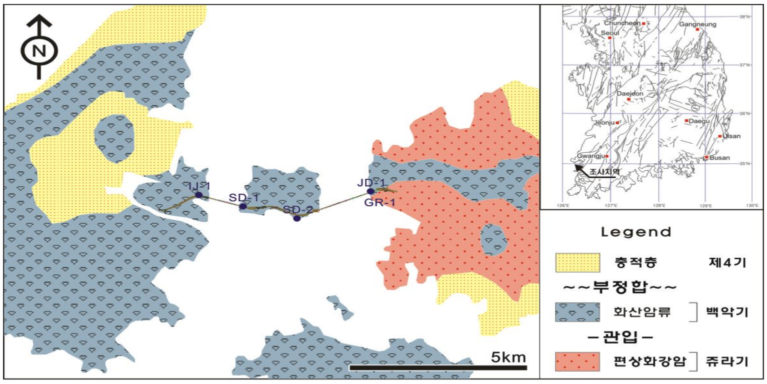
<Table 2.3> Evaluation of weathering grade using the weathering index (Sueoka, 1988)

<table>
<tr><th>CWI (%)</th><th>Division</th><th>Extent of weathering</th><th>Classification of weathered granite</th></tr>
<tr><td>13-15</td><td>I</td><td>Fresh Rock</td><td>Fresh Rock</td></tr>
<tr><td rowspan="3">15-20</td><td>II</td><td>Slightly Weathered</td><td rowspan="3">Weathered Granite</td></tr>
<tr><td>III</td><td>Moderately Weathered</td></tr>
<tr><td rowspan="2">IV</td><td rowspan="2">Highly Weathered</td></tr>
<tr><td rowspan="2">20-40</td><td rowspan="2">Granular disintegration sand<br>Masado soil</td></tr>
<tr><td>V</td><td>Completely Weathered</td></tr>
<tr><td>40-60</td><td>VI</td><td>Residual soil</td><td>Lateritic soil</td></tr>
<tr><td>60-90</td><td>VII</td><td>Weathered Hard pan<br>(as cemented)</td><td>Laterite or bauxite</td></tr>
</table>

# Chapter 3. Strength and Permeability Characteristics through Weathering Acceleration Experiments

## 3.1 The geographical and geological features of the target region for this study

The target region for this study is an island area ranging from Imja-myoen to Jido-eup in Sinan-gun, Jeollanam-do (Jido, Imjado, Sudo), where a mountain system and hilly mountainous areas in the northwestern to southeastern direction have developed and some of rocky coastal lands have been formed due to wind and waves. The intertidal zones are widely distributed along the curvy coastline, and breakwater and farmland have been developing owing to phased land reclamation projects.




<Figure 3.1> Geological map of the study areas

These areas are mostly composed of acidic volcanic rocks (tuff, beschtauile, felsic rocks) with various textures and structures, and some of the areas have beschtauile and felsite. Tuff and tuff breccia are distributed as irregular mixtures throughout the target region. Beschtauile is highly resistant to weathering and displays a good lithologic state as an aggregate of acidic volcanic rocks, which frequently alternates with other rock types. Felsic rocks are abundant in the Sudo area with the tuff type penetrating intensively therein, and it was shown that they contained 85.9% minerals that were resistant to weathering such as quartz and feldspar.

## 3.2 Sampling and sample molding

Rock samples for the weathering sensitivity experiments were collected in Jido, Imjado, and Sudo by rock types. Slight weathering was seen in most outcrops and schistose granite did not show the outcrop. From each sample, specimen was taken and polished pieces were made, followed by the analysis. Samples were pulverized, for which X-ray diffraction, X-ray fluorescence, acid submersion reaction and the chemical analysis of this reaction were carried out for the analysis of the degree of chemical weathering. Cores with 1 inch and 2 inch diameters, respectively, were molded and experiments were performed to determine the characteristics of weathering reduction.

| Coring of sample (NX, BX) | Grinding of sample (Dia. 1inch) |
|---|---|
|  | <br>permeability test sampling<br> |

<Figure 3.2> Sampling of the grab sample

Various accelerated weathering experiments were carried out with the polished pieces and specimen made out of the collected samples as seen in <Table 3.1>.

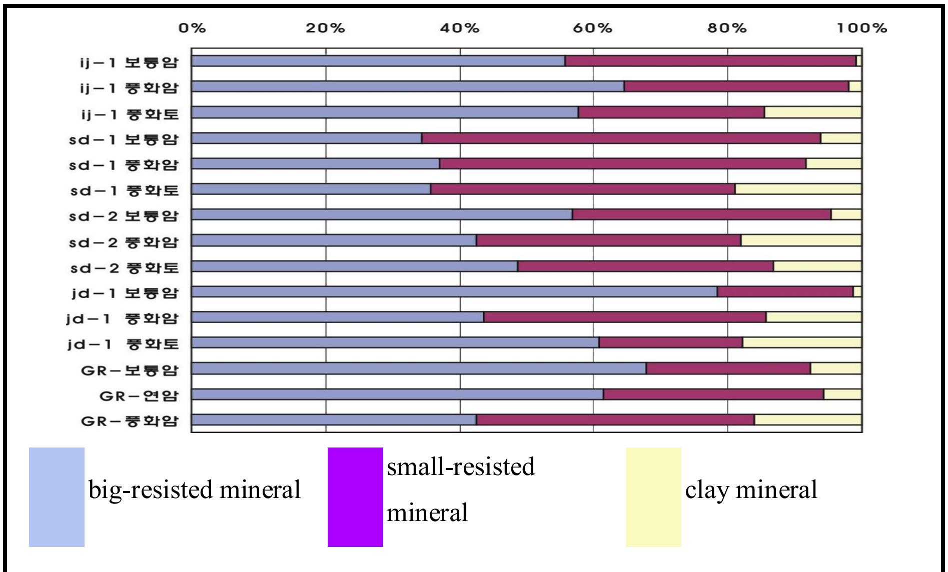
<Table 3.1> Summary of weathering acceleration experiments list

| classification | | volcanic rock | beschtauile | Felsite | flake granite |
|---|---|---|---|---|---|
| chemical characteristic | X-RD analysis | 5 | 6 | 1 | 3 |
| | X-RF analysis | 5 | 6 | 1 | 3 |
| | ICP-MS | 5 | 6 | 1 | 3 |
| mechnical | durability abrasion | 1 | 2 | 1 | 1 |
| weathering reduction | absorption | 40 | 80 | 40 | 40 |
| | permeability test | 25 | 25 | 4 | 21 |
| | joint shear test | 1 | 1 | 1 | 1 |
| grinding sample | stereoscopic | 13 | 23 | 12 | 8 |
| | SEM | 8 | 16 | 8 | 8 |

## 3.3 The chemical weathering sensitivity experiment and analysis

### 3.3.1 Analysis of the weathered minerals through the X-ray diffraction (X-RD)

Clay minerals secondarily created as weathering progresses are one of those that accelerate weathering. The safety of artifacts can be predicted by determining the presence of swelling minerals. The quantitative analysis was carried out by pulverizing the selected samples using a ball-mill after drying them at low temperature in dryer, and representing 2θ on the horizontal axis and the diffraction strength on the vertical axis for the x-ray diffraction data of so powdered samples.




<Figure 3.3> Result of X-RD analysis by study area sample

The x-ray diffraction analysis of bedrocks distributed in the research area showed crystalline minerals such as quartz, plagioclase, k-feldspar, mica, dolomite and other minerals including diopside, and illite, kaolin, and chloriteand. Smectite that is one of swelling clay minerals was observed in some samples.

Smectite was observed in the weathered rocks on Jido with high content ratio of 8.5-9.4%, and the distribution of this swelling mineral becomes a factor to reduce the strength of ground. The content of clay minerals was 0.9-19.0%, which was relatively low in bedrocks, but increased to a maximum of 19.0% in weathered rocks. The content of clay minerals was increasing as weathering progressed, and the clay minerals of the weathered soil were shown to be increased up to 8.5-16.5% content in the bedrocks.

Diopside was observed in the bedrocks taken from Sudo, which indicated a different rock type from that of Imjado and Jido. Despite the outcrops of Jido (JD-1) being the same, the correlation of the mineral composition between normal rocks, weathered rocks and weathered soil was considered to be low. In the case of usual rocks that show a relatively fresh state, it is thought that they contained 76.6% of quartz corresponding to were felsite. Since only segments that were physically highly resistant to weathering, it was considered that weathering has progressed in the form of weathered rocks and soil in the segments of volcanic rocks that were relatively vulnerable to weathering.

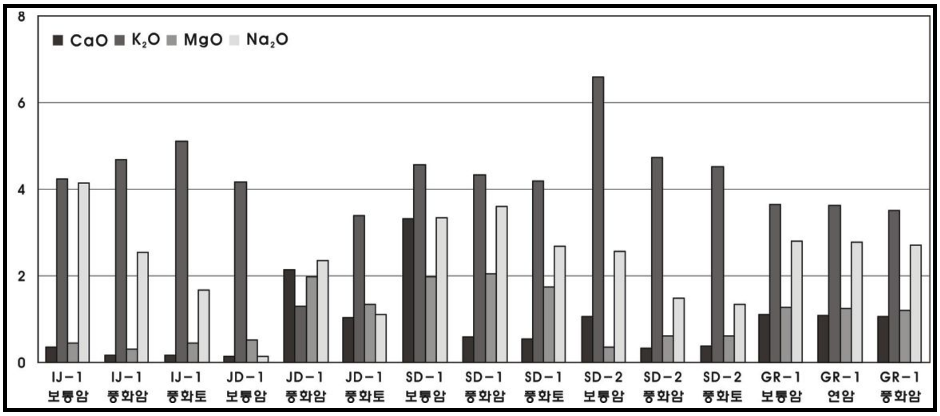
As for schistose granite, it was shown that 5-7% of clay minerals were distributed in normal rocks and soft rocks while weathered rocks had approximately as high as 16% of the clay minerals.

The weathering resistance was shown to decrease in the order of felsite, schistose granite, and volcanic rocks (beschtauile), and the content of clay minerals in rocks in which weathering has progressed was approximately 16%, showing a similar range of values.

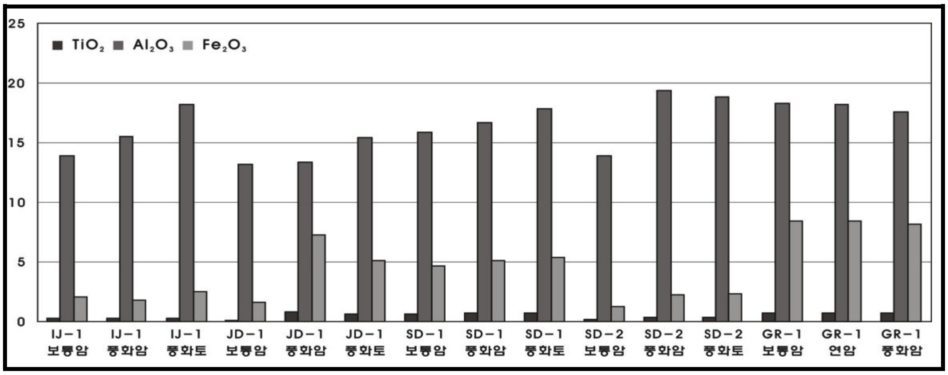
### 3.3.2 Estimation of the weathering index through the whole rock analysis (X-RF)

By using the leaching characteristics for weathering, the degree of weathering was determined by measuring the ratio of chemical species with greater mobility (alkali metal, alkaline earth metal) and those with smaller mobility (TiO2, Al2O3, Fe2O3). Si, Mg, Ca, and Na are leached during the weathering, and Al and Ti are concentrated as residues in the system. On the other hand, K and Fe show more complex behaviors, and K is usually leached when the weathering has progressed and the soil is formed.

When a solution (hot water) penetrates into the system, K+ is utilized to form K- minerals and adsorbed to clays through ion exchange. Otherwise, it may be removed by flowing fluid. The weathering index was calculated using the composition of chemical species from the results of the whole rock analysis.




<Figure 3.4> Result of the whole rock analysis (big chemical species)

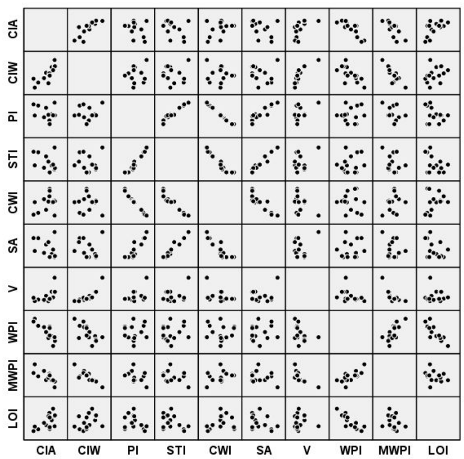



<Figure 3.5> Result of the whole rock analysis (small chemical species)

<Table 3.2> Weathering index through the whole rock test analysis

| classification | | CIA | CIW | CWI | PI | SA | V | Si-Ti index | WPI | MWPI |
|---|---|---|---|---|---|---|---|---|---|---|
| IJ-1 | moderate rock | 61.38 | 75.54 | 16.20 | 82.05 | 5.25 | 3.67 | 82.83 | 7.87 | 9.57 |
| | weathered rock | 67.80 | 85.19 | 17.59 | 80.54 | 4.62 | 6.73 | 81.16 | 5.01 | 8.09 |
| | weathered soil | 72.43 | 90.81 | 21.11 | 76.29 | 3.67 | 10.17 | 77.57 | 3.14 | 7.99 |
| SD-1 | moderate rock | 58.56 | 70.45 | 1.15 | 75.41 | 3.97 | 2.37 | 77.59 | 11.15 | 14.33 |
| | weathered | 66.19 | 79.89 | 22.54 | 74.29 | 3.78 | 3.36 | 76.63 | 7.30 | 11.70 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | rock | | | | | | | | | |
| | weathered soil | 70.60 | 84.64 | 23.87 | 72.14 | 3.36 | 4.41 | 74.86 | 2.51 | 10.55 |
| SD-2 | moderate rock | 57.58 | 79.27 | 15.39 | 82.79 | 5.26 | 5.14 | 83.00 | 9.84 | 10.86 |
| | weathered rock | 74.76 | 91.47 | 21.96 | 75.10 | 3.36 | 9.99 | 76.00 | 1.56 | 7.79 |
| | weathered soil | 75.12 | 91.66 | 21.56 | 75.53 | 3.47 | 0.07 | 76.53 | 0.87 | 7.52 |
| JD-1 | moderate rock | 74.84 | 97.95 | 14.94 | 83.97 | 5.86 | 1.72 | 84.70 | 2.62 | 5.19 |
| | weathered rock | 69.77 | 74.84 | 21.42 | 75.90 | 4.86 | 2.27 | 79.09 | 2.23 | 9.03 |
| | weathered soil | 73.62 | 87.84 | 21.20 | 5.56 | 4.11 | 5.43 | 77.89 | -1.44 | 8.00 |
| GR-1 | moderate rock | 70.80 | 82.42 | 27.49 | 9.75 | 3.37 | 4.25 | 74.82 | 7.49 | 9.92 |
| | soft rock | 70.80 | 82.42 | 27.32 | 9.75 | 3.37 | 4.25 | 74.82 | 6.85 | 9.92 |
| | weathered rock | 70.80 | 82.42 | 26.44 | 9.75 | 3.37 | 4.25 | 74.82 | 3.41 | 9.92 |

| Correalationship between chemical index | | Min. | Max. | Aver. | standard deviation |
|---|---|---|---|---|---|
|  | CIA | 7.58 | 5.12 | 69.00 | 5.72 |
| | CIW | 0.45 | 7.95 | 83.79 | 7.35 |
| | PI | 9.75 | 3.97 | 75.92 | 4.66 |
| | STI | 4.82 | 4.70 | 78.15 | 3.30 |
| | CWI | 4.94 | 7.49 | 21.35 | 4.01 |
| | SA | 3.36 | 5.86 | 4.11 | .85 |
| | V | 2.27 | 1.72 | 6.54 | 4.97 |
| | WPI | 1.44 | 1.15 | 4.69 | 3.57 |
| | MWPI | 5.19 | 4.33 | 9.36 | 2.13 |
| | LOI | .80 | 8.20 | 3.93 | 2.25 |



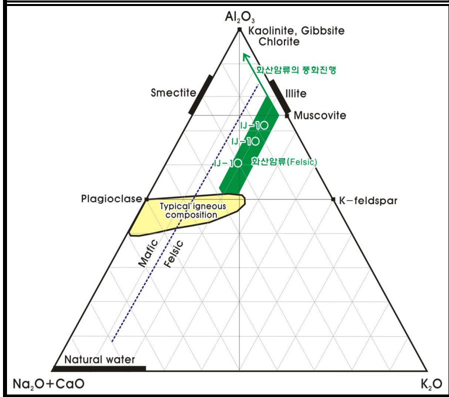
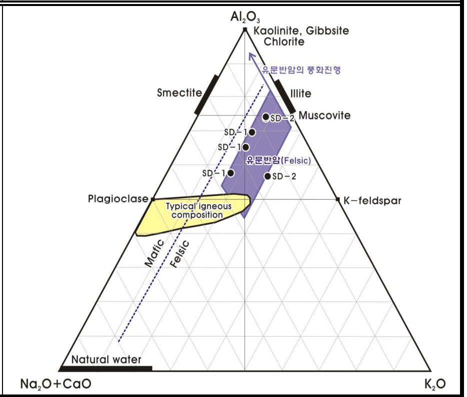
<Figure 3.6> Correalationship between chemical index

Most of weathering indices show correlations with 2 or more of other weathering indices, and CIA shows a high correlation with 5 weathering-related indices such as CIW, V, WPI, MWPI, and LOI at the level of 0.05 and 0.01.

While other weathering indices do not have any specific criteria for a single rock and mineral, in the case of the chemical index of alteration (CIA), the range of weathering index is determined for rocks and minerals and consequently it is easy to identify the degree of weathering through the correlation analysis with different index values. Since the CIA shows a high correlation with other indices, the weathering index of the research area was determined using the CIA.

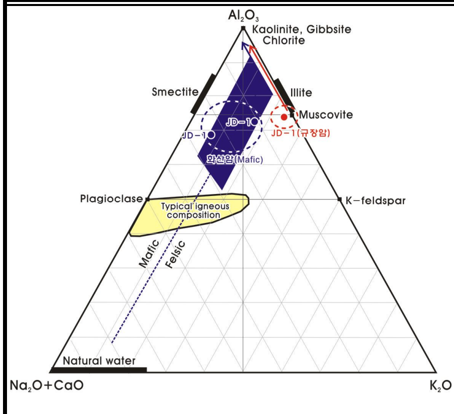
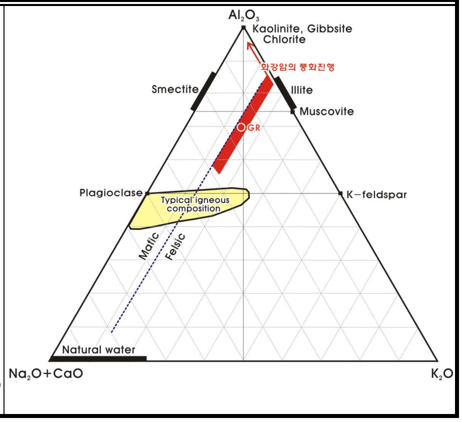
### 3.3.3 Estimation of the chemical index of alteration (CIA)

The weathering index (chemical index of alteration) of fresh granite and volcanic rocks (andesite) ranges from 45 to 55, which increases as weathering advances, and becomes nearly 100 as it is closer to a completely weathered soil. The results of the CIA analysis on volcanic rocks, beschtauile, sohistose granite, and felsite in research area were compared with those of volcanic rocks from Yuchon group and Jurassic granite measured in Korea.

| volcanic rock CIA Diagram (Imja island) | Beschtauile CIA Diagram (Su island) |
|---|---|
|  |  |



<Figure 3.7> Distribution chart of CIA at volcanic rock

| Felsite/volcanic rock CIA Diagram (Ji island) | Flake granite CIA Diagram (Ji island) |
|---|---|
|  |  |



<Figure 3.8> Distribution chart of CIA at other rocks

Most of the samples are acidic rock (felsic), and the weathering path of bedrock-illite-kaolin can be seen in these rocks. Even though it belongs to the same outcrop, the relatively fresh rock of Jido is felsite and shows the characteristics of acidic rock. The area that shows severe weathering of the same outcrops is a differential weathering region of volcanic rocks, which shows the characteristics of mafic rocks. These belong to intermediate or basic volcanic rocks, and are highly likely to follow the path of bed rock-smectite-kaolin with the progress of weathering. The mineralogical quantitative analysis of these areas shows the high content of smectite.

When compared with the values for volcanic rocks and Jurassic granites in Korea, the research area showed that weathering was much advanced compared to the fresh rock. Also, weathering has progressed much on schistose granite compared with the value range of the fresh granite.

### 3.3.4 Estimation of the chemical weathering rate through the analysis of cation dissolution

Since there is a limit in predicting the chemical weathering rate of the entire slope only with an accelerated dissolution test for samples collected from the drilling core, a prediction model for the rates of chemical weathering that accommodates main factors such as weathering factors for the natural environment and acid rain in a specific area was applied.

While rocks react with neutral or alkaline groundwater at pH 7-8 before the exposure on the surface, textures of rocks and minerals become damaged by atmospheric pressure after the exposure and the exposed rocks face the accelerated weathering by directly reacting with acid rain generated by air pollution. Air pollutants discharged to the atmosphere turn into strong acids including sulfuric acid, nitric acid and hydrochloric acid by chemical reactions with rain, fog and snow, with their pH falling below 5.6. They are called acid rain, acid fog and acid snow, and causative substances are sulfur dioxide and nitrogen oxides. These substances move and spread into the atmosphere, and undergo chemical transformations to become sulfuric acid and nitric acid, which eventually oxidize rain.

Exposed rocks act as a direct factor of the accelerated weathering with physical and chemical reactions caused by acid rain and air pollution, and the weathering sensitivity and grade can be estimated by applying the chemical weathering rate prediction Profile Model with natural environment and acid rain as main factors.

The acceleration of the cation leaching indicates the reduction of the resistance to weathering by joints and cracks, and the slow cation leaching rate in the sample in the process of weathering reflects that the amount of cation that can be leached by weathering already has been reduced. In general, as weathering is progressed, the cation leaching rate tends to be reduced with reduction in the amount of cation that is to be leached by weathering. However, the faster leaching rate in samples, in which weathering has progressed, indicates that those samples will be weathered rapidly in the future.

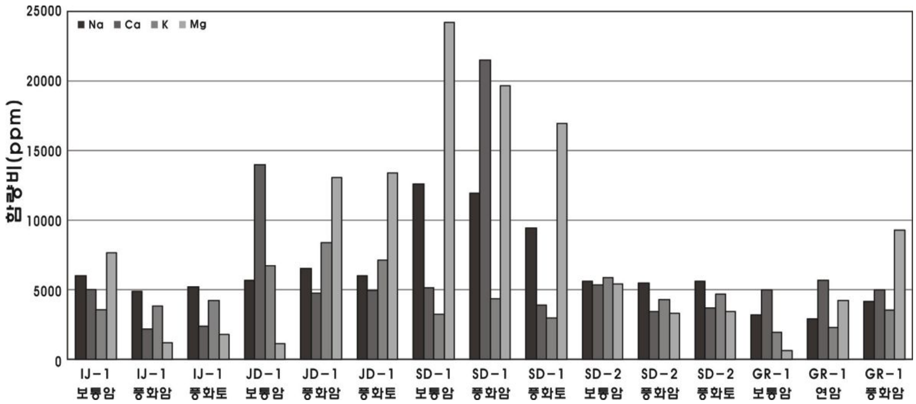
<Table 3.3> Chemical weathering velocity grade

| grade | amount of critical load (kEq/ha/yr) | weathering controlled minerals | mother rock |
|---|---|---|---|
| 1 | < 0.2 | Quartz, K-feldspar | Granite, Quartzite |
| 2 | 0.2 ~ 0.5 | Muscovite, Plagioclase, Biotite(<5%) | Granite, Gneiss |
| 3 | 0.5 ~ 1.0 | Biotite, Ampibolite(<5%) | Granodiorite, Greywacke, Schist |
| 4 | 1.0 ~ 2.0 | Pyroxene, Epidote, Olivine(<5%) | Gabbro, Basalt |
| 5 | > 2.0 | Carbonates | Limestone, Marl |

※ Chemical weathering classification established at Skokloster in 1988, Nilsson & Grenfeld

Increase in the cation leaching rate indicates the reduction in the weathering resistance by joints and cracks, and the slow cation leaching rate in sample in the process of weathering reflects that cation that can be leached by weathering in the future already has been reduced by the preceding weathering.

In general, as weathering is progressed, the cation leaching rate tends to be reduced with the decrease in the amount of cation that is to be leached due to weathering. However, the faster leaching rate in samples, in which weathering has progressed, indicates that those samples will be weathered rapidly in the future.




<Figure 3.9> Result of positive ion elution response

In the cation dissolution test, the high content ratio of dissolving ion was measured in SD-1 and JD-1, and some samples turned light brown upon reaction during ion dissolution by sulfuric acid. While this indicates that the possibility of acid drainage leak cannot be ruled out on the surface when reacted with acid rain in the future, the mineral analysis suggested that sulfide minerals such as pyrite was not generated.

## 3.4 The mechanical weathering sensitivity experiment and analysis

### 3.4.1 The evaluation of slake durability

Slake durability proposed by Franklin and Chandra (1972) indicates the relative grade of durability against the alteration of rocks. The analysis was performed according to the ASTM D 4644 that is a standard method to represent slaking characteristics quantitatively.

The slake durability index (Id) is calculated by the following equation, and the index after the second cycle, Id2, has usually been adopted.

$$I_{d2} = \frac{B}{A} \times 100\%,$$

A: Initial dry weight, B: Weight of residual sample after test

While the slake durability test is generally interpreted using residues after the two 10 minute rotations, the analysis was performed after three rotations to increase the precision.

<Table 3.4> Classification by slake durability index (Goodman,1980)

| classification | Residuals after rotation 10min/1 times(%) | Residuals after rotation 10min/2 times(%) |
|---|---|---|
| very high durability | > 99 | > 98 |
| high durability | 98 ~ 99 | 95 ~ 98 |
| middle-high durabilty | 95 ~ 98 | 85 ~ 95 |
| middle durability | 85 ~ 95 | 60 ~ 85 |
| low durability | 60 ~ 85 | 30 ~ 60 |
| very low durability | < 60 | < 30 |

<Table 3.5> Result of slake durability test

| classification | ground | I1 | I2 | I3 | evaluation |
|---|---|---|---|---|---|
| SD-1 | soft rock | 99.9 | 99.5 | 99.0 | very high durability |
| SD-2 | soft rock | 99.9 | 99.9 | 99.5 | |
| IJ-1 | soft rock | 100.0 | 99.8 | 99.3 | |
| JD-1 | soft rock | 99.8 | 99.5 | 99.2 | |
| GR-1 | moderate rock | 100.0 | 99.9 | 99.9 | |

A slake durability test showed that all rocks had extremely high durability.

## 3.5 The weathering reduction experiment and analysis

As the cut slope is exposed to air for a long period after securing the initial stability, its stability becomes weakened by weathering due to different climatic conditions or changes in hydraulic conditions. Fracture will happen in soft/hard rocks with little weathering mainly due to the state change of filling material within joint and the long-term strength reduction of joint, which result from chemical weathering by weathering and strong rainfall.

To evaluate the stability of rock slopes due to the long-term weathering, the prediction of strength reduction characteristics of long-term properties were attempted by carrying out chemically and mechanically accelerated weathering tests. Samples (weathered rock / soft rock / hard rock) were prepared and molded by rock types and by weathering stages, and the accelerated weathering experiments were carried out. The experimental conditions are as follows and the process was repeated for 7 days: saturation in distilled water at pH 2 and 80℃ for 12 hours ➡ melting at room temperature (accelerating chemical and mechanical weathering)

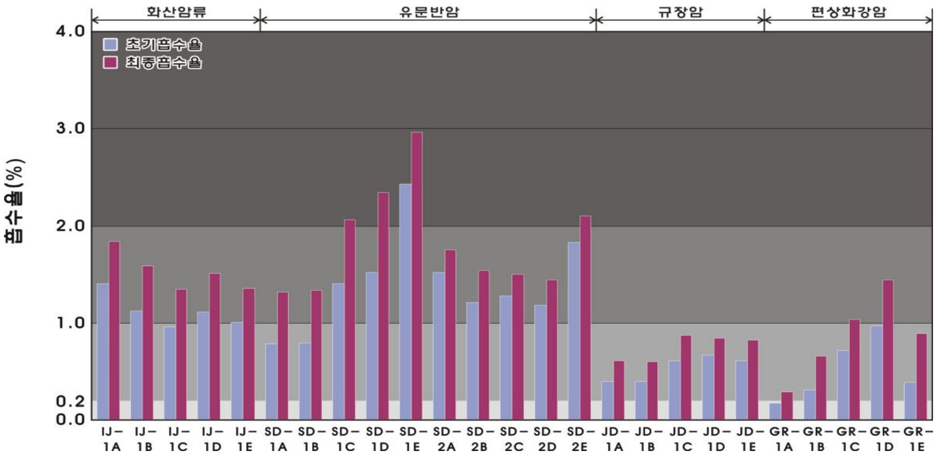
The absorption rate in the beginning of a test in order to determine the initial state of weathering, and the changed absorption rate after a weathering test was measured to identify the degree of change.

### 3.5.1 Absorption rate test

In order to determine the extent of weathering according to repetitive acid submersion and freeze-thaw of rocks, the observation of the changes in material properties and the prediction of the degree of weathering were attempted by measuring absorption rates. The absorption rate test of rocks was carried out in accordance with KS F 2503, and the equation of the absorption rate is as follows.

$$\text{Absorption rate} = \{(M_{sat}-M_{dry})/M_{dry}\} \times 100\ (\%)$$

In general, the absorption rate increases when rocks are weathered according to the weathering resistance, and negative correlation between the absorption rate and the uniaxial compression strength is observed. The absorption rate test showed that it increased in all stratum and the increase was greater in the order of felsite, schistose granite, vocanic rocks and beschtauile. The initial absorption rate of felsite was low and its change was not significant while the initial absorption rate of beschtauile was shown to be higher than 1.0 and its change was observed to increase by a maximum of 0.82%.




<Figure 3.10> Result of absorption rate test

<Table 3.6> Change of absorption before and after test

| classification | before test(%) | after test(%) | change rate(%) | classification | before test(%) | after test(%) | change rate(%) |
|---|---|---|---|---|---|---|---|
| IJ-1A | 1.40 | 1.84 | +0.44 | SD-2D | 1.18 | 1.44 | +0.26 |
| IJ-1B | 1.12 | 1.59 | +0.47 | SD-2E | 1.83 | 2.10 | +0.27 |
| IJ-1C | 0.96 | 1.35 | +0.39 | JD-1A | 0.40 | 0.61 | +0.21 |
| IJ-1D | 1.11 | 1.51 | +0.40 | JD-1B | 0.40 | 0.60 | +0.21 |
| IJ-1E | 1.01 | 1.36 | +0.35 | JD-1C | 0.61 | 0.87 | +0.26 |
| SD-1A | 0.78 | 1.32 | +0.54 | JD-1D | 0.67 | 0.84 | +0.18 |
| SD-1B | 0.79 | 1.34 | +0.54 | JD-1E | 0.61 | 0.82 | +0.21 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SD-1C | 1.40 | 2.06 | +0.65 | GR-1A | 0.17 | 0.29 | +0.12 |
| SD-1D | 1.52 | 2.34 | +0.82 | GR-1B | 0.31 | 0.66 | +0.35 |
| SD-1E | 2.43 | 2.96 | +0.54 | GR-1C | 0.72 | 1.04 | +0.32 |
| SD-2A | 1.52 | 1.75 | +0.23 | GR-1D | 0.97 | 1.44 | +0.47 |
| SD-2B | 1.21 | 1.54 | +0.33 | GR-1E | 0.39 | 0.89 | +0.51 |
| SD-2C | 1.28 | 1.50 | +0.22 | | | | |

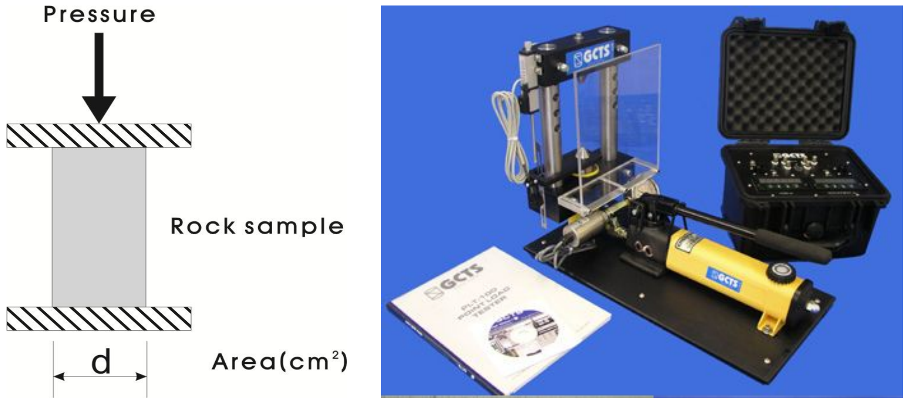
### 3.5.2 Uniaxial compression test

In order to determine the degree of weathering due to repetitive acid submersion and freeze-thaw of rocks, the uniaxial compression strength of the original sample and its value after the weathering test were compared and analyzed through the uniaxial compression strength test.

Given P is the breaking load and A is the cross-sectional area of the specimen under compressive force in an uniaxial compression test, then the uniaxial compression strength is calculated from the following equation.

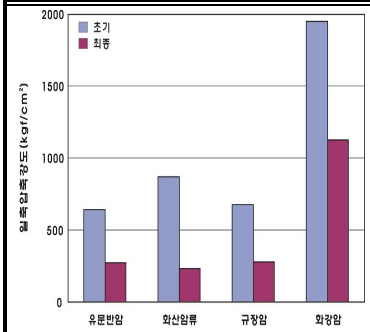
$$\sigma_c = \frac{P}{A}$$

In this experiment, the uniaxial compression strength test of rocks was carried out using the specimen with a diameter of 2.5 cm, and as for a test equipment, PLT-100 (GCTS, US) was used.

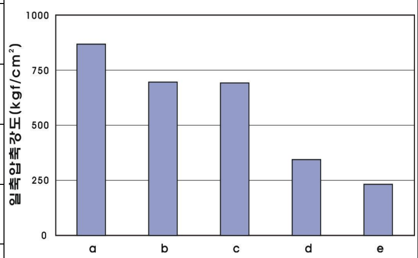
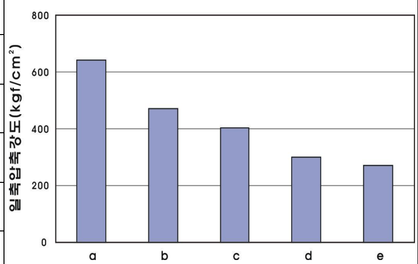


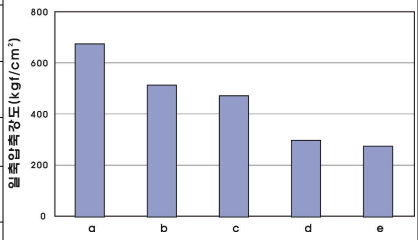
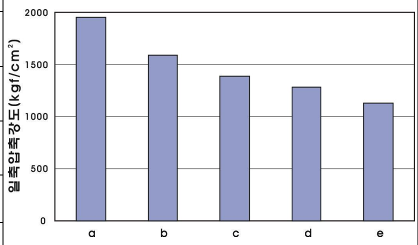

<Figure 3.11> Diagram and equipment of uniaxial compressive strength

The uniaxial compression strengths before and after the freeze-thaw test were measured by making 1 inch sized specimen of rocks collected from the outcrop. The value for the schistose granite was shown to be high compared to that measured with 1 inch-core since it was converted by measuring the point load strength. The initial uniaxial compression strengths were 867.15 kgf/cm2, 640.90 kgf/cm2, and 674.86 kgf/cm2 in volcanic rocks, beschtauile, and felsite, respectively, and the uniaxial compression strength of the schistose granite converted through the point load test was found to be 1951.27 kgf/cm2.

| change of uniaxial compression strength | before test | after test |
|---|---|---|
|  |  |  |

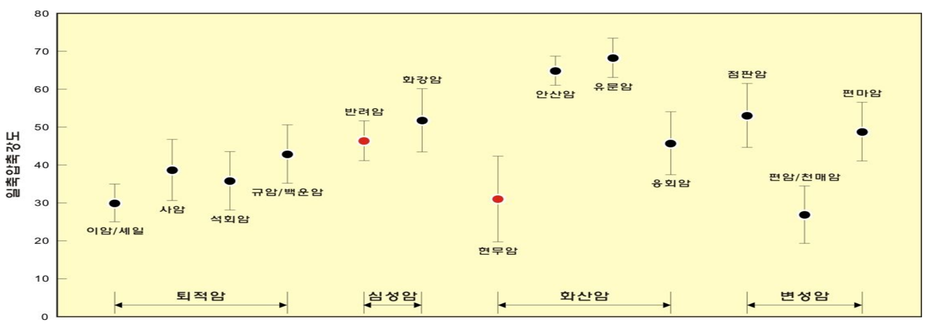
<Figure 3.12> Change of uniaxial compressive strength before and after the test

| change of uniaxial compression strength | | | | change rate |
|---|---|---|---|---|
| classification | | uniaxial compression strength(kgf/cm2) | number | |
| volcanic rock | IJ-1a | 867.15 | 0 |  |
| | IJ-1b | 697.14 | 1 | |
| | IJ-1c | 691.73 | 3 | |
| | IJ-1d | 342.19 | 5 | |
| | IJ-1e | 230.58 | 7 | |
| | change rate | 73.4% | | |
| Beschtauil e | SD-1a | 640.90 | 0 |  |
| | SD-1b | 469.80 | 1 | |
| | SD-1c | 402.55 | 3 | |
| | SD-1d | 299.79 | 5 | |
| | SD-1e | 270.59 | 7 | |
| | change rate | 42.6% | | |

| | | | | |
|---|---|---|---|---|
| Felsite | JD-1a | 674.86 | 0 |  |
| | JD-1b | 513.06 | 1 | |
| | JD-1c | 473.05 | 3 | |
| | JD-1d | 299.79 | 5 | |
| | JD-1e | 277.08 | 7 | |
| | change rate | 58.9% | | |
| Flake granite | GR-1a | 1951.27 | 0 |  |
| | GR-1b | 1591.61 | 1 | |
| | GR-1c | 1383.27 | 3 | |
| | GR-1d | 1282.13 | 5 | |
| | GR-1e | 1125.60 | 7 | |
| | change rate | 42.3% | | |



<Figure 3.13> Change of uniaxial compressive strength by rock types




<Figure 3.14> Distribution of internal uniaxial compressive strength

by rock types

If basalt is excluded that generated pores during the cooling process, the uniaxial compression strengths by rock types decreased in the order of igneous rock (volcanic rock), igneous rock (plutonic rock), metamorphic rock and sedimentary rock. Igneous rock showed higher strength in basic rock rather than acidic rock. It is considered that there is no correlation between formative ages and strength since the uniaxial compression distribution of rocks by geologic age showed almost no changes.

The uniaxial compression strengths by rock types decreased in the order of rhyolite, andesite, slate, granite, gneiss, gabbro, tuff, quartzite/dolomite, sandstone, limestone, basalt, mudstone/shale, and schist/phyllite, which showed that phyllite, schis and rocks composed of mudstone and shale were the weakest in strength. Since the strength of rocks is reduced in proportion to weathering, areas developing the large scale fault or fold belt are expected to show low strength regardless of rock types.

### 3.5.3 Measurement of the elastic wave velocities

As one of the biggest causes of mechanical weathering is the temperature changes, the material properties change when rocks freeze and thaw accompanied by the reduction in strength of the rocks. The observation of the changes in material properties of rocks and the prediction of weathering were attempted by measuring the elastic wave velocities according to the forced weathering of rocks.

The elastic wave velocities before and after the phased weathering reduction test were measured for rocks collected from the outcrops. The bedrock distributed in the target research area was classified by rock types into group A, and the elastic wave velocities were shown to be 5.25 km/sec, 3.98~6.24 km/sec, and 5.13~6.46 km/sec in weathered rock, soft rock, and normal rock, respectively.

<Table 3.7> Standard of rock classification(comparison between group A and B)

| classification | A | B |
|---|---|---|
| Typical rock | gneiss, sand schist, green schist, hornstone, lime stone, sand stone, celadon tuff, psephite, granite, diorite, peridotite, shale, andesite, basalt | black schist, green schist, celadon tuff, shale, mud stone, tuff, agglomerate rock |
| Visual inspection by components | It contains much sand material, quartz and has stiff rock quality and has high crystallinity | It doesn't have sand material, quarts, tuff material and has phyllite material |
| Decision by hitting 500-1000gr hammer | Rock of hitting point becomes small flat rock fragment and almost doesn't leave rock material | Rock of hitting point becomes small flat rock fragment and almost doesn't leave rock material |

parallel at surface, the most rapid direction of seismic velocity

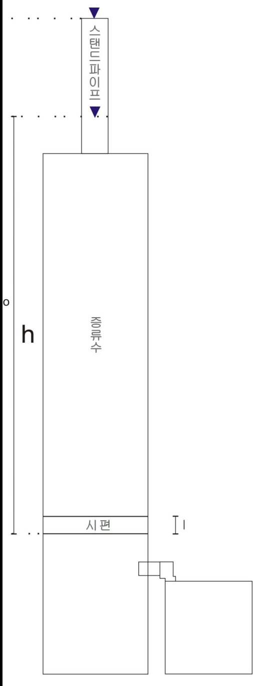
<Table 3.8> Seismic velocity by rock types

<table>
<tr><th colspan="2">Group of rock type</th><th>natural seismic velocity</th><th>seismic velocity of rock</th><th>note</th></tr>
<tr><td rowspan="2">weathered rock</td><td>A</td><td>0.7 - 1.2 ㎞/sec</td><td>2.0 - 2.7 ㎞/sec</td><td rowspan="9">·sample:<br>thickness 15 ~ 20㎝<br><br>·method of measurement:<br>X axis (parallel at surface, the most rapid direction of seismic velocity)</td></tr>
<tr><td>B</td><td>1.0 - 1.8 ㎞/sec</td><td>2.5 - 3.0 ㎞/sec</td></tr>
<tr><td rowspan="2">soft rock</td><td>A</td><td>1.2 - 1.9 ㎞/sec</td><td>2.7 - 3.7 ㎞/sec</td></tr>
<tr><td>B</td><td>1.8 - 2.8 ㎞/sec</td><td>3.0 - 4.3 ㎞/sec</td></tr>
<tr><td rowspan="2">moderate rock</td><td>A</td><td>1.9 - 2.9 ㎞/sec</td><td>3.7 - 4.7 ㎞/sec</td></tr>
<tr><td>B</td><td>2.8 - 4.1 ㎞/sec</td><td>4.3 - 5.7 ㎞/sec</td></tr>
<tr><td rowspan="2">hard rock</td><td>A</td><td>2.9 - 4.2 ㎞/sec</td><td>4.7 - 5.8 ㎞/sec</td></tr>
<tr><td>B</td><td>≥ 4.1 ㎞/sec</td><td>≥ 5.7 ㎞/sec</td></tr>
<tr><td colspan="2">super hard rock</td><td>≥ 4.2 ㎞/sec</td><td>≥ 5.8 ㎞/sec</td></tr>
</table>

The elastic wave velocities after the phased weathering test were measured in the research area. The initially measured value before a test was 5.56 km/sec (3.98-6.46km/sec) on average, corresponding to normal rocks, and the value after the weathering test was 5.30 km/sec (3.95-6.13km/sec), likewise normal rocks. Consequently, changes in elastic wave velocities before and after weathering were not found to be significant.

### 3.5.4 Permeability changes by permeability tests

The range of permeability coefficient of the ground is very broad depending on the size of the particles. A variable-head permeability test that determines the permeability coefficient by investigating the relationship between drawdown and the elapsed time when penetrating into samples with a certain diameter and length was carried out to identify changes in the permeability coefficient due to weathering caused by repetitive acid immersion and freeze-thaw of rocks.




Inflow flow rate per unit time

$$Q = -adv = -a\frac{dh}{dt} = Av = Aki = Ak\frac{h}{l}$$

$$dt = -\frac{al}{Ak}\frac{dh}{h}$$

ater level h0 at t0 time, if water level h at t time,

$$\int_{t_0=0}^{t} dt = -\frac{al}{Ak}\int_{h_0}^{h}\frac{dh}{h}$$

$$t - t_0 = -\frac{al}{Ak}\ln\frac{h}{h_0}$$

$$= \frac{al}{Ak}\ln\frac{h_0}{h}$$

$$k = \frac{al}{A(t-t_0)}\ln\frac{h_0}{h} = 2.3\frac{al}{A(t-t_0)}\log\frac{h_0}{h}$$

<Figure 3.15> Summary of variable head permeability test

Based on domestic and international literature data associated with permeability coefficient by rock types, the impact of the pore microstructure of domestic granitic rocks found in Pocheon, Boryeong, and Yangsan on hydromechanical characteristics was shown in <Table 3.9>. Morris and Johnson proposed the representative hydraulic conductivity of geologic materials.

Average permeability coefficient of volcanic rocks increased from 1.45E-08 (1.35E-08~1.59E-08) before the weathering test to 2.90E-07 (4.03E-08~1.35E-06) after the weathering test. Average permeability coefficient of beschtauile was shown to increase from 1.18E-08 (9.78E-09~1.47E-08) before the weathering test to 4.42E-07 (3.29E-08~3.58E-06) after the weathering test. Average permeability coefficient of felsite increased from 3.67E-09 to 1.85E-08 (1.33E-08~2.20E-08), and that of schistose granite did so from 1.49E-07 (5.85E-08~8.14E-07) before the weathering test to 1.19E-07 (1.00E-07~1.34E-07) after the weathering test.

<Table 3.9> Impact of the pore micro structure on hydromechanical characteristics(2012)

| sample | control mode | | Permeability (m2) | Permeability (mD) |
|---|---|---|---|---|
| Pocheon granite | Constant pressure | 100 psi | 2.0×10-17 | 2.0×10-2 |
| | | 200 psi | 2.3×10-17 | 2.3×10-2 |
| | | 300 psi | 2.5×10-17 | 2.5×10-2 |
| | | 500 psi | 2.8×10-17 | 2.8×10-2 |
| | | 700 psi | 3.2×10-17 | 3.2×10-2 |

| | | | | |
|---|---|---|---|---|
| Yangsan granite | | 700 psi | 1.2×10-19 | 1.2×10-4 |
| | | 1000 psi | 1.8×10-19 | 1.8×10-4 |
| | | 1200 psi | 1.2×10-19 | 1.2×10-4 |
| Boryung sandstone | | 700 psi | 4.6×10-21 | 4.6×10-6 |
| | | 1200 psi | 3.9×10-21 | 3.9×10-6 |
| Berea sandstone (perpendicular to bedding) | Constant flow rate | 1.0mℓ/min | 3.5×10-16 | 0.35 |
| | | 1.5mℓ/min | 4.2×10-16 | 0.42 |
| | | 2.0mℓ/min | 4.9×10-16 | 0.49 |
| | | 2.5mℓ/min | 5.8×10-16 | 0.58 |
| Berea sandstone (parallel to bedding) | | 1.0mℓ/min | 1.3×10-14 | 13 |
| | | 1.5mℓ/min | 1.0×10-14 | 10 |
| | | 2.0mℓ/min | 1.1×10-14 | 11 |
| | | 2.5mℓ/min | 1.7×10-14 | 17 |
| Berea sandstone (oblique(45°) to bedding) | | 1.0mℓ/min | 3.7×10-16 | 0.37 |
| | | 1.5mℓ/min | 4.3×10-16 | 0.43 |
| | | 2.0mℓ/min | 5.1×10-16 | 0.51 |
| | | 2.5mℓ/min | 6.5×10-16 | 0.65 |

<Table 3.10> Typical hydraulic conductivity of geologic materials

(Morris and Johnson,1967)

| materals | hydraulic conductivity(m/day) | shape of measurement |
|---|---|---|
| Gravel, Coarse | 150 | disturbed sample |
| Gravel, medium | 270 | disturbed sample |
| Gravel, fine | 450 | disturbed sample |
| Sand, Coarse | 45 | disturbed sample |
| Sand, medium | 12 | disturbed sample |
| Sand, fine | 2.5 | disturbed sample |
| Silt | 0.08 | horizontal conductivity |
| Clay | 0.0002 | horizontal conductivity |
| Sandstone, Fine-grained | 0.2 | vertical conductivity |

| | | |
|---|---|---|
| Sandstone, medium-grained | 3.1 | vertical conductivity |
| Limestone | 0.94 | vertical conductivity |
| Dolomite | 0.001 | vertical conductivity |
| Dune Sand | 20 | vertical conductivity |
| Loess | 0.08 | vertical conductivity |
| Peat | 5.7 | vertical conductivity |
| Schist | 0.2 | vertical conductivity |
| Slate | 0.00008 | vertical conductivity |
| Till, Predominantly sand | 0.49 | disturbed sample |
| Till, Predominantly gravel | 30 | disturbed sample |
| Tuff | 0.2 | vertical conductivity |
| Basalt | 0.01 | vertical conductivity |
| Gabbro, weathered | 0.2 | vertical conductivity |
| Granite, weathered | 1.4 | vertical conductivity |

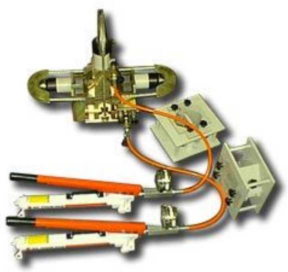
<Table 3.11> Change of permeability coefficient by rock types before and after weathering

| before weathering | | | | after weathering | | | |
|---|---|---|---|---|---|---|---|
| classification | permeability coefficient | | average | classification | permeability coefficient | | average |
| volcanic rock | 1.47E-08 | 1.35E-08 | 1.45E-08 | volcanic rock | 1.07E-06 | 9.31E-08 | 2.90E-07 |
| | 1.53E-08 | 1.41E-08 | | | 3.57E-07 | 7.72E-08 | |
| | 1.59E-08 | - | | | 2.79E-07 | 5.28E-08 | |
| | 1.47E-08 | - | | | 3.08E-07 | 4.03E-08 | |
| | 1.47E-08 | - | | | 4.35E-07 | 4.53E-08 | |
| | 1.35E-08 | - | | | 1.35E-06 | 5.85E-08 | |
| | 1.41E-08 | - | | | 7.32E-08 | 4.92E-08 | |

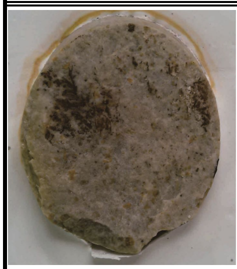
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1.47E-08 | - | | | 5.99E-08 | - | |
| beschtauile | 1.22E-08 | 1.35E-08 | 1.18E-08 | beschtauile | 3.58E-06 | 5.29E-08 | 4.42E-07 |
| | 1.10E-08 | 9.78E-09 | | | 5.46E-07 | 5.17E-08 | |
| | 1.16E-08 | - | | | 2.79E-07 | 3.52E-08 | |
| | 1.41E-08 | - | | | 1.61E-07 | 3.29E-08 | |
| | 1.47E-08 | - | | | 1.22E-07 | 3.34E-08 | |
| | 1.04E-08 | - | | | 1.50E-06 | 4.38E-08 | |
| | 9.78E-09 | - | | | 8.79E-08 | 3.68E-08 | |
| | 1.10E-08 | - | | | 6.38E-08 | - | |
| felsite | 3.67E-09 | - | 3.67E-09 | felsite | 2.20E-08 | 2.01E-08 | 1.85E-08 |
| | - | - | | | 1.33E-08 | - | |
| flake granite | 8.14E-07 | 5.85E-08 | 1.49E-07 | flake granite | 1.34E-07 | - | 1.19E-07 |
| | 1.76E-07 | 7.33E-08 | | | 1.24E-07 | - | |
| | 1.84E-07 | 8.78E-08 | | | 1.17E-07 | - | |
| | 1.22E-07 | 7.55E-08 | | | 1.00E-07 | - | |
| | 1.36E-07 | 7.48E-08 | | | - | - | |
| | 9.51E-08 | 7.33E-08 | | | - | - | |
| | 2.05E-07 | 6.90E-08 | | | - | - | |
| | 1.32E-07 | 6.89E-08 | | | - | - | |
| | 9.56E-08 | - | | | - | - | |

## 3.5.5 Joint shear test

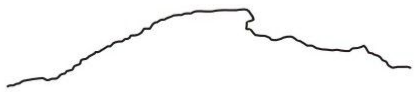
Joint shear test was carried out to measure the maximum and residual shear strength in rocks before and after the weathering reduction test. The equipments and specifications used in the test are shown in <Fig. 3.16> and each test specimen by rock types is shown in <Fig. 3.17>.

| test equipment | specifications |
|---|---|
|  | ·Rock shear Box, Portable to ASTM D5607, ISRM, SL900(Impact Test Equipment Ltd, UK)<br>2 Hydraulic Pumps<br>2 Pressure Gauges<br>2 Pressure Pipes<br>1 Dial Gauge 25mm×0.01 divisions<br>2 Aluminium formers with Perspex sides |

<Figure 3.16> Equipments and specifications of joint shear test

| beschtauile | volcanic rock | felsite | flake granite |
|---|---|---|---|
|  |  |  |  |

<Figure 3.17> Sample used joint shear test by rock types

<table>
<tr><th>classification</th><th>roughness profile</th><th>JRC</th></tr>
<tr><td>beschtauile</td><td></td><td>2-4</td></tr>
<tr><td>volcanic rock</td><td></td><td>4-6</td></tr>
<tr><td rowspan="3">felsite</td><td></td><td>10-12</td></tr>
<tr><td></td><td>0-2</td></tr>
<tr><td></td><td>12-14</td></tr>
<tr><td>flake granite</td><td></td><td>16-18</td></tr>
</table>

<Figure 3.18> Joint roughness profile by rock types

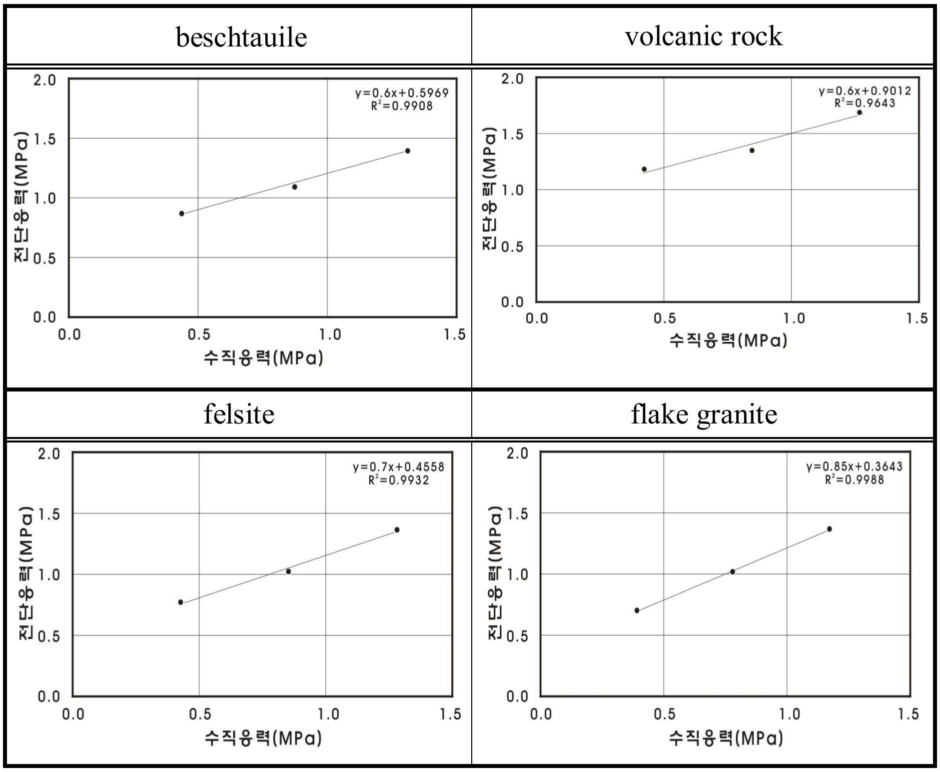
<Table 3.12> Cohesion and internal friction angle by rock types

| classification | cohesion(MPa) | friction angle(°) | weathering level |
|---|---|---|---|
| beschtauile | 0.597 | 30.96 | MW |
| volcanic rock | 0.901 | 30.96 | |
| felsite | 0.456 | 34.99 | |
| flake granite | 0.364 | 40.36 | |

<Table 3.13> Reduction rate of internal friction angle before and after weathering

| classification | internal friction angle(°) | | reduction rate(%) |
|---|---|---|---|
| | bibliographic data* | measurement value | |
| beschtauile | 37.5-41.3 | 30.96 | 17.4-25.0 |
| volcanic rock | | 30.96 | |
| felsite | | 34.99 | 6.7-15.3 |
| flake granite | | 40.36 | (-)7.1-2.3 |

※"engineering property about joint shear strength of main rock ditributed in korea(2001)"



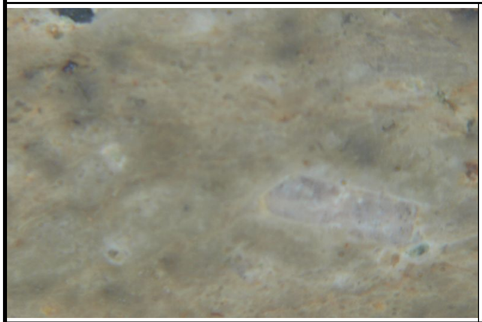
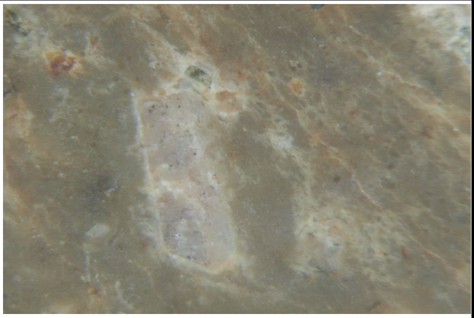
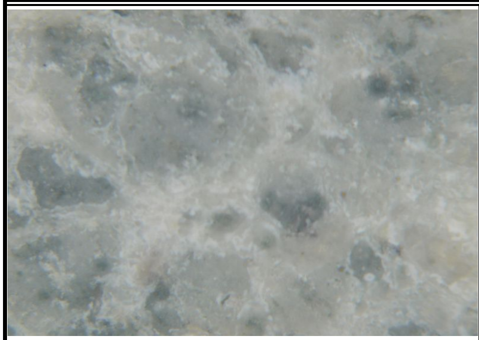
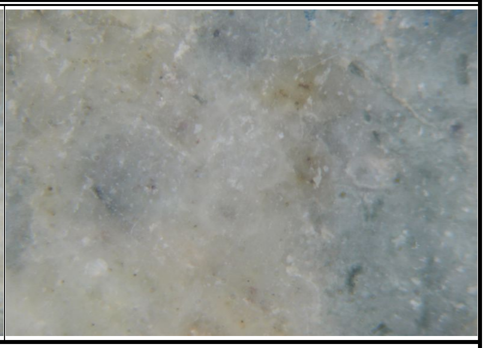

<Figure 3.19> Relation between shear stress and normal stress by rock types

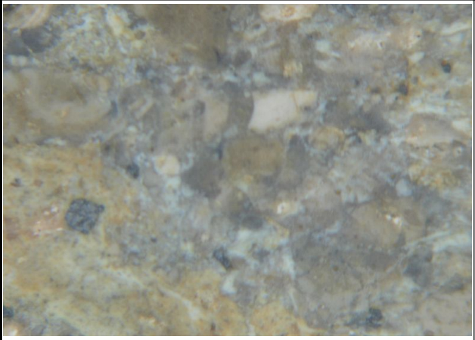
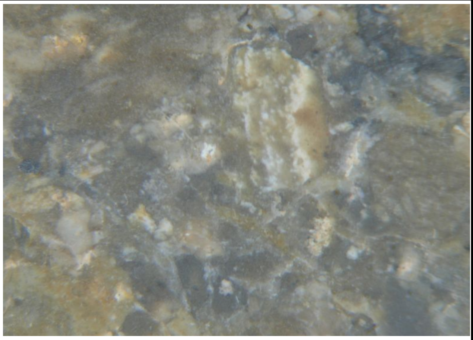
The friction angles of granite, andesite, and tuff from literature data were applied as internal friction angles before the weathering reduction test, and found to be the range of 37.5-41.3 °. The joint shear test for bedrocks of the research area showed that the friction angles of beschtauile and volcanic rocks after the weathering reduction test were identical both 30.96°. Felsite and granite were 34.99° and 40.36°, respectively, which indicated the reduction rate of 2.3 - 25.0% depending on rock types. The reduction rate increased in the order of granite, felsite and beschtauile=volcanic rocks.

The granite in this study was a schistose granite and the joint was made artificially for a test due to the lack of the natural joint. It had greater roughness compared to other samples, displaying relatively low reduction rate of 2.3%.

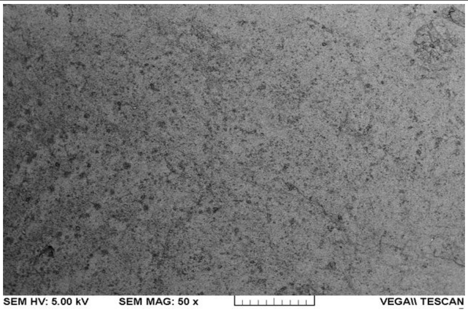
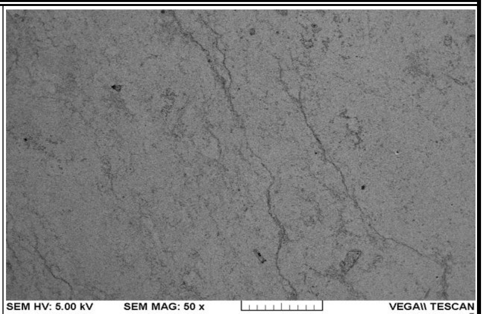
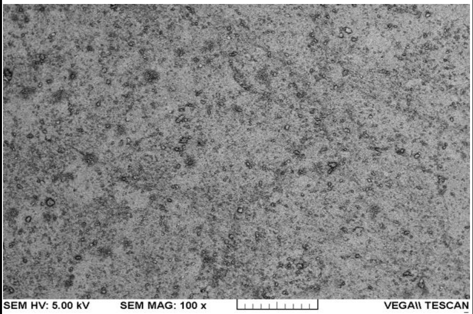
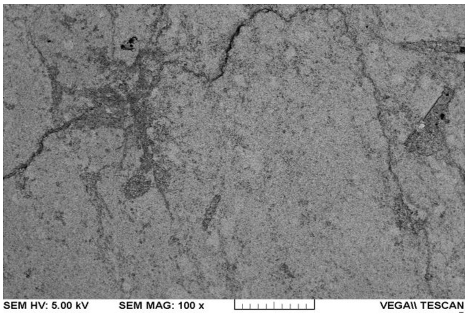
## 3.6 Surface changes on rocks due to weathering

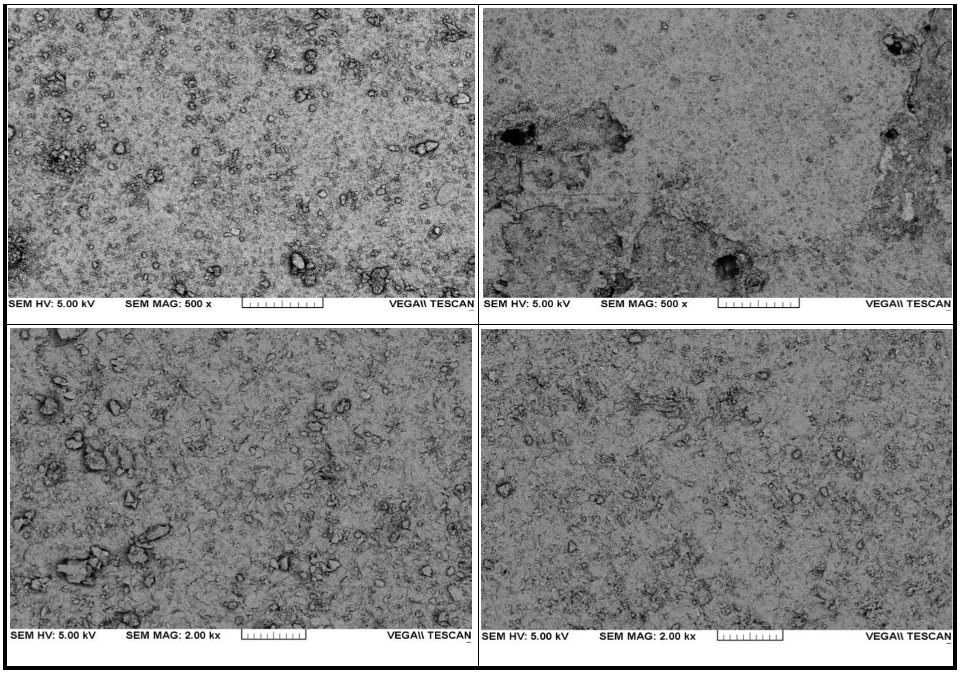
A stereoscopic microscope with 40-200X magnification was used to observe surface changes on rocks due to weathering, and an electron microscope that has higher magnification than a stereoscopic microscope was used for more precise observations. A high magnification scanning electron microscope (SEM) used in this study was Hitachi S-2700 of Japan.

| volcanic rocks | |
| --- | --- |
| before weathering | after weathering |
|  |  |
| beschtauile | |
| before weathering | after weathering |
|  |  |
| felsite | |

<table>
<tr><th>before weathering</th><th>after weathering</th></tr>
<tr><td></td><td></td></tr>
</table>

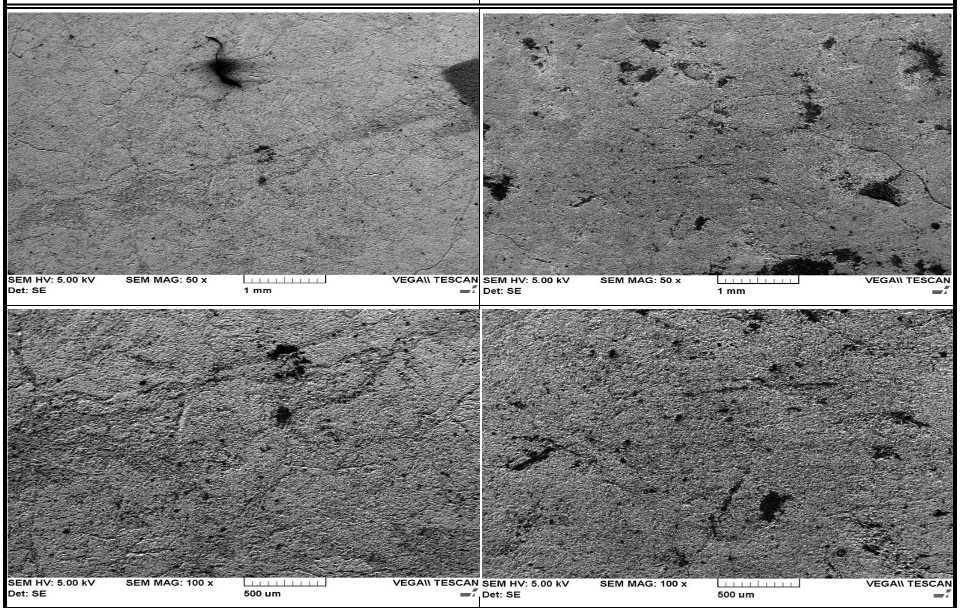
<Figure 3.20> Change of rock surface by stereoscopic microscope observation

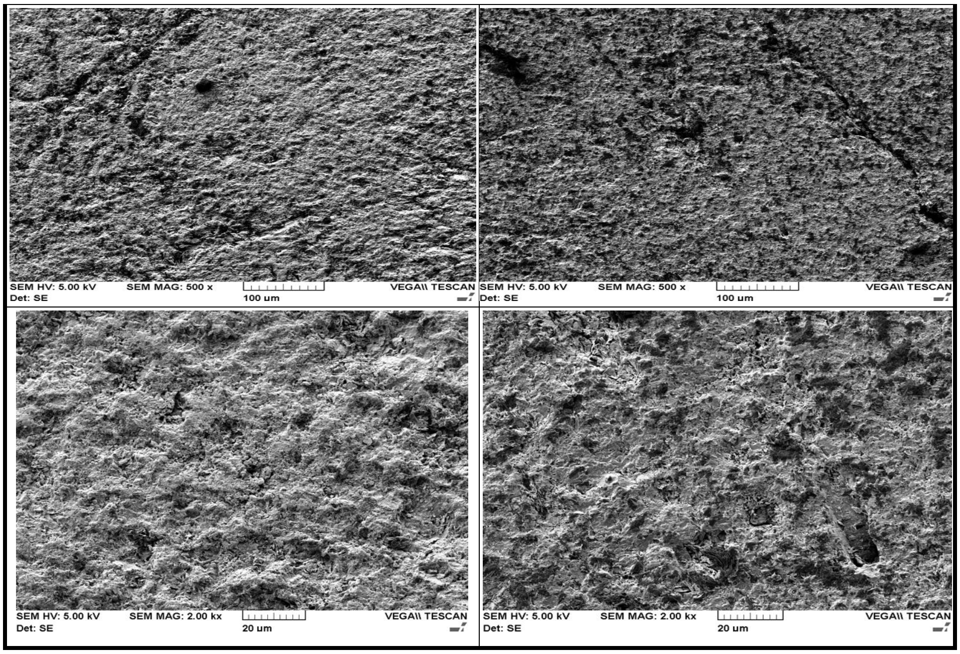
<table>
<tr><th colspan="2">volcanic rocks (IJ-1)</th></tr>
<tr><th>before weathering</th><th>after weathering</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>




<Figure 3.21> Change of rock surface by SEM observation(volcanic rocks)

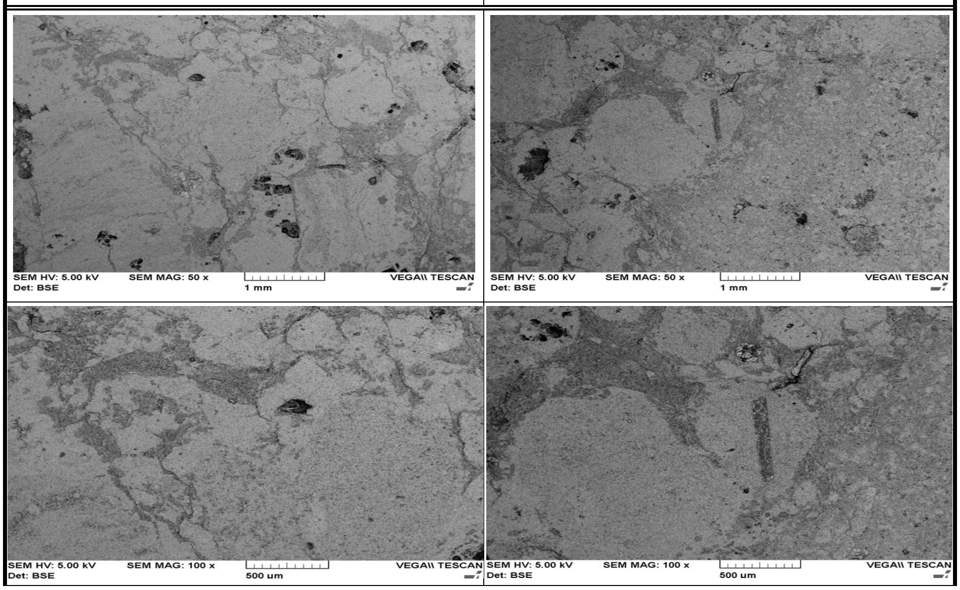
| beschtauile (SD-1) | |
|---|---|
| before weathering | after weathering |

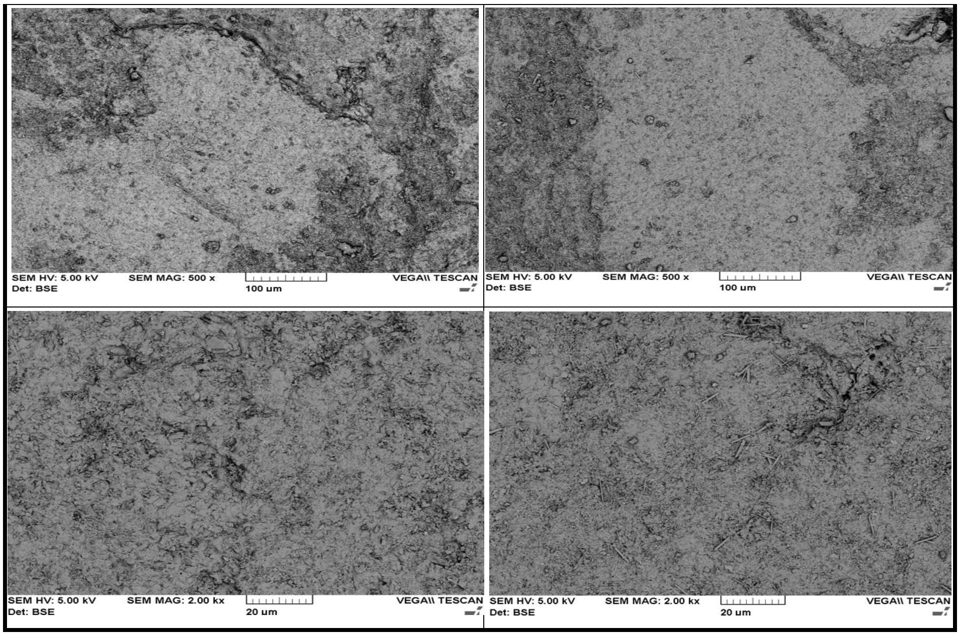





<Figure 3.22> Change of rock surface by scanning electron microscope (SEM) observation(beschtauile)

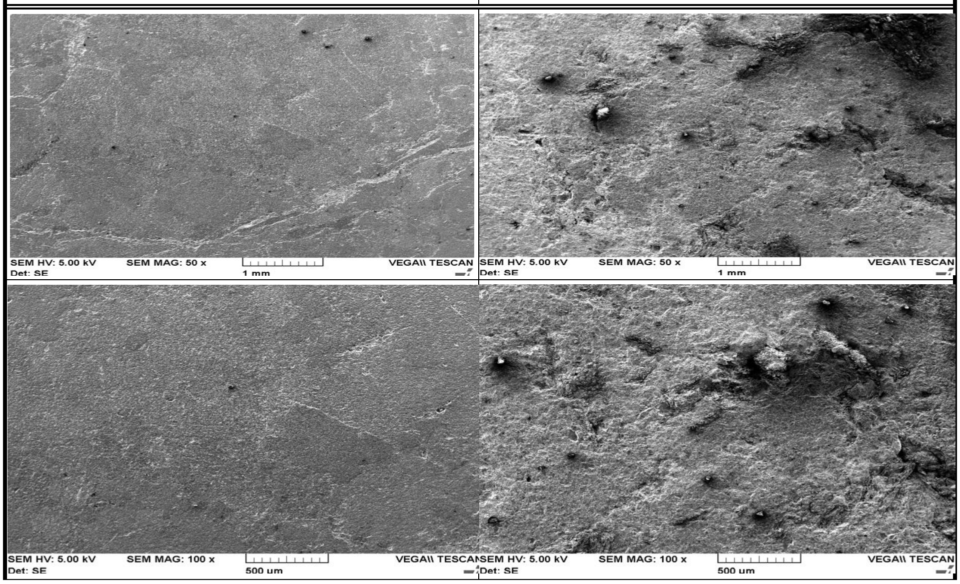
| felsite (JD-1) | |
|---|---|
| before weathering | after weathering |

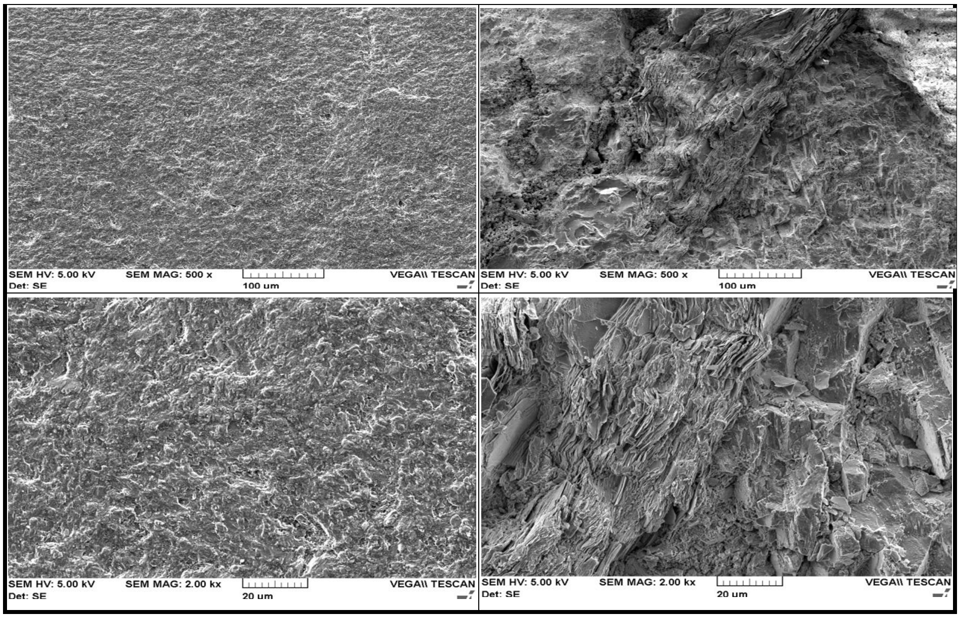





<Figure 3.23> Change of rock surface by SEM observation(felsite)

| flake granites (GR-1) | |
|---|---|
| before weathering | after weathering |






<Figure 3.24> Change of rock surface by SEM observation(flake granite)

Although significant changes were not observed on the surface of rocks before and after weathering by the stereoscopic microscope, weathering was shown to be progressing around the mineral crystal face, and it was found that some minerals were deposited as the surface reacted with acids. Also, significant changes were not observed by the SEM. However, some mineral crystal textures were found to become loose.

## 3.7 Weathering grades by rock types based on the results of the weathering tests

The changes and reduction in soil properties according to rock types in this research area can be predicted using the values obtained through the weathering sensitivity analysis and the weathering reduction test.

<Table 3.14> Grade of weathering sensitivity

| grade | expression | description |
|---|---|---|
| 1 | non-sensitive | Felsite non-developed discontinuity |
| 2 | almost non-sensitive | Hard sand stone with compact organization and non-developed discontinuity |
| 3 | little sensitive | Andesite a little-developed discontinuity |
| 4 | ordinary sensitive | Granites developed discontinuity / Bedrock developed with calcite |
| 5 | very sensitive | Shale with 10% above content of swelling minerals and well-broken |

<Table 3.15> Evaluation of weathering grade by rock types

| classification | mineral | weathering | absorption | reduction | synthesis |
|---|---|---|---|---|---|
| volcanic rock | 4-5 | 3-4 | 3-4 | 3-4 | 4 |
| beschtauile | 4-5 | 2-3 | 3-4 | 3-4 | 3-4 |
| felsite | 1-2 | 1-2 | 1-2 | 1-2 | 1-2 |
| flake granite | 2-3 | 3-4 | 2-3 | 2-3 | 3 |

The evaluation of the weathering grades by rock types showed that both beschtauile and volcanic rocks had the grades of 3~4, indicating higher sensitive to weathering compared to other rocks. Therefore, care must be taken when constructing the civil engineering structures such as rock slopes since they are more vulnerable to weathering with longer exposure to the atmosphere.

# Chapter 4. Conclusion

In this thesis, the changes and reduction in soil material properties such as strength and permeability of rocks due to long weathering were analyzed through the weathering sensitivity analysis and the weathering reduction test in volcanic rocks distributed in island region of Sinan, Jeollanam-do.

Weathering mineral elements that compose volcanic rocks were identified, and the weathering rates and indices were calculated through the chemical weathering sensitivity analysis such as x-ray diffraction and whole rock analysis. In addition, the post-weathering durability of rocks was evaluated through the slake durability test that was a mechanical weathering sensitivity test.

The changes in strength and permeability before and after weathering were determined by the tests for absorption rates, permeability, elastic wave velocity, uniaxial compression strength and joint shear that were physical weathering factors. The surface changes on rocks were observed before and after weathering through the analysis by the stereoscopic microscope and the scanning electron microscope using the polishing pieces of samples.

Conclusions drawn in this thesis through various accelerated weathering tests in the volcanic rock area are as follows.

1. Analysis of weathered minerals through X-ray diffraction showed that crystal minerals such as quartz, plagioclase, orthoclase, mica, dolomite and diopside as well as others including illite, kaolin, and chlorite were observed, and in some sample swelling smectite was also found. Smectite was observed in weathered rocks from the Jido area, and its content was as high as 8.5 - 9.4%. Since the distribution of such swelling minerals isafactorin reducing the ground strength, it is considered that caution is needed when constructing civil engineering structures such as the slope.

2. The resistance to weathering decreased in the order of felsite, sohistose granite, and volcanic rocks (beschtauile), and the content of clay minerals in weathered rocksshowed a similar range of values in all samples, which was

approximately 16%. Most of the samples were acidic rocks (felsic) and a weathering path of bedrock-illite-kaolin was indicated in these rocks. Some intermediate or alkaline volcanic rocks also appeared and it is considered that these are highly likely to follow a path of bedrock-smectite-kaoline with the progress of weathering. It was shown that weathering of bedrock in the research area was much advanced compared to the fresh rock, and the state of schistose granite indicated that weathering has progressed extensively if compared with the value range of the fresh granite.

3. The cation dissolution test showed that the high ratio of the dissolving ions by strong acid was measured at SD-1 and JD-1, and some samples turned light brown upon reaction during the dissolution of ions by sulfuric acid. This indicates that the possibility of the acid drainage leak cannot be ruled out on the ground surface in a reaction with acid rain in the future. However, it was found that sulfide minerals such as pyrite was not observed in the mineral analysis.

4. Slake durability test for the analysis of mechanical weathering sensitivity showed extremely high durability in all rocks.

5. The absorption rates increased in the order of felsite, schistose granite, volcanic rocks and beschtauile. The initial absorption rate of felsite was low

and the change in the absorption rate was not substantial while the initial absorption rate of beschtauile was higher than 1.0 and its increase was up to a maximum of 0.82%.

6. The measurement of the uniaxial compression strength of rocks before and after weathering showed that the strength reduction was 73.4% in volcanic rocks, 42.6% in beschtauile, 58.9% in felsite and 42.3% in schistose granite, which generally showed a substantial reduction in strength, compared to initial strength. In particular, the post-weathering strength reduction in volcanic rocks was the largest.

7. The elastic wave velocities after the phased weathering test were measured. The initially measured value was 5.56 km/sec (3.98-6.46 km/sec) on average and that after the weathering test was 5.30 km/sec (3.95-6.13 km/sec), all of which corresponded to normal rocks. It was found that changes in elastic wave velocities were not significant.

8. The average permeability coefficient increased from 1.45E-08 (1.35E-08~1.59E-08) before the weathering test to 2.90E-07 (4.03E-08~1.35E-06) after the weathering test in volcanic rocks, from 1.18E-08 (9.78E-09~1.47E-08) before the weathering test to 4.42E-07 (3.29E-08 ~3.58E-06) after the weathering test in beschtauile, from 3.67E-09 before the weathering test to

1.85E-08 (1.33E-08~2.20E-08) after the weathering test in felsite, and from 1.49E-07 (5.85E-08~8.14E-07) before the weathering test to 1.19E-07 (1.00E-07 ~1.34E-07) after the weathering test in schistose granite.

9. Joint shear test for bedrocks in the research area showed that the internal friction angle of both beschtauile and volcanic rocks was 30.96° after the weathering reduction test, and those of felsite and granite were 34.99° and 40.36°, respectively. The reduction rate was shown to be 2.3 - 25.0% depending on the rock types and increased in the order of schistose granite, felsite and beschtauile=volcanic rocks. The granite in this study was a schistose granite and the joint was made artificially for a test due to the lack of the natural joint. It had greater roughness compared to other samples, displaying relatively low reduction rate of 2.3%.

10. No substantial changes on the surface of rocks before and after weathering were observed by the stereoscopic microscope and the scanning electron microscope. However, it is considered that the amount of cracks or gaps increases on the surface of rocks with the progress of weathering since it was observed that the textures of some mineral crystals have become loose.

11. In this thesis, the reduction rate of soil properties was suggested through accelerated weathering tests in the volcanic rock area. Through these experimental data, it is expected that the reliable design and construction will be possible in selecting the reasonable surface protection methods and estimating their range when planning civil engineering structures such as rock slopes in the future.

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# 초 록

최근 국가경제 발전과 공업화에 따라 도로개설 공사가 증가되면서 선형을 양호하게 하기 위하여 불가피하게 대절토 비탈면이 빈번하게 조성되고 있다. 암반비탈면은 절취와 동시에 대기환경에 노출되면서 풍화가 진행되어 강도저하가 발생된다.

그동안 화강암이나 퇴적암 등에서 풍화에 관한 연구는 많이 진행되었으나 화산암에 대한 풍화 연구는 매우 미미한 실정이다. 따라서 본 논문에서는 화산암 구간에 암반 비탈면 조성시 풍화가속실험을 수행하여 장기 풍화에 따른 암반 물성치 변화를 정량적으로 예측하고자 하였다.

화학적 풍화민감도 분석을 통해 현재 화산암 구간의 풍화광물을 파악하였고 화학적 풍화지수와 변질지수를 산정하여 정량적인 풍화등급을 제시하고자 하였다. 또한 암반의 풍화전후 내구성 파악을 위하여 기계적 풍화민감도 분석인 슬레이킹 내구성 실험을 수행하였다.

흡수율, 탄성파 속도, 투수계수, 일축압축강도, 절리면 전단실험 등 물리적 풍화지수와 관련된 실험을 수행하여 풍화전후 암석의 강도 및 투수성 변화를 정량적으로 예측하고자 하였다.

실제 풍화된 암반 비탈면의 표면변화를 관찰하고자 실체 현미경과 주사전자 현미경 분석을 통해 풍화전후 암석 표면의

변화를 관찰하였다.

화산암 구간에서 이러한 풍화가속실험을 통해 산출된 암반 물성치들은 실제 토목구조물 계획시 풍화를 고려한 합리적인 설계 및 시공이 되도록 기초자료를 제공하고자 한다.

**주요어 : 화산암, 장기풍화, 풍화지수, 풍화가속시험, 풍화등급**

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