Weathering effects on engineering properties of Schist of Menderes Massif, West of Turkey

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ABSTRACT
Schist is a metamorphic rock type that is widely exposed in the Western Anatolia. Schist of Menderes Massif is located in different locations and geological levels. The rock is mainly used as a filling and building material in the present and in foreseeable future. Usage of schist as filling materials in dams is related with their weathering degree which affects their geomechanical properties. To determinate the petrographic, chemical, index and engineering properties of the schist used as filler material in the dams/small dam crest, fresh and weathered samples of rock material were collected from quarries. The relationship between the weathering degree index and engineering properties were determined by simple regression analyses¹. The results show that the studied parameters of physical and mechanical properties of the studied schist have a positive correction with weathering grade. Thus, increasing weathering grade affects the durability of the schist thereby compromising its applicability.

Keyword: Menderes Massive, Schist, Weathering, XRF, Porosity, Water content

Introduction
The Menderes massif Schist, which outcrops in wide areas in the Aegean Region, have been studied intensively by several researchers from past to present [1-10]. These weak rock resources are usually required for use as filling material to provide cost saving and minimize environmental impact. Determining the correct failure parameters of weak schist is very important for a safer design of dam [11]. Due to the presence of planes of weakness and the low water resistance of schist, very detailed field and laboratory tests are required. Weathering of constituent minerals in schist may contribute to occurrence of these weak planes (i.e. schistosity) which affect the strength and deformational behaviors of the rocks [12, 13].

To determine weathering effects on geomechanical properties of schist, three rock quarries were studied within the Menderes Massive schist. These were; Burgaz dam in Bayındır-İzmir, Arslanlar small dam in Torbalı-İzmir and Yenişehir small dam in Tire- İzmir. Chemical, petrographical, physical
and mechanical properties of the schist were determined on samples collected from dam quarries (Figure 1).

Several researchers have indicated that engineering properties of rock materials are affected by weathering [14-17]. According to Ruxton [18], if SiO₂/Al₂O₃ ratio is smaller than 2.9, it means that the rock material is highly weathered. Che, et.al [13] presented data on the density, chemistry and mineralogical composition of weathering of Tertiary basalt in Limbe, Cameroon. They established that CIA (Chemical Index of Alteration) showed a positive correlation with bulk density and porosity. Oke et.al. [19], studied about intensity of weathering of the mafic rocks such as muscovite schist, amphibolite, talc schist and quartz schist and they defined in order of the intensity of weathering by using Ruxton Ratio. To determinate weathering grade of Andesitic rocks around İzmir weathering index parameters were used and it gave good results [17, 16]. Khanlari et.al [16] studied about weathering effects on engineering properties of Alavand granitoid, Iran. Their study showed that when the weathering grade increase, the engineering properties of rocks decrease. In addition, they found that as the weathering grade increases, the percentage of Fe₂O₃, Loss on Ignition (LOI), and TiO₂ increase, but the percentage of SiO₂, Na₂O, K₂O and CaO decrease. Some authors have mainly focused on SiO₂ which has a positive correlations with K₂O and negative correlations with CaO, TiO₂ and Cr for chlorite schist [20]. Weathering Index of Parker (WIP) was applied for silicate rocks [21]. The WIP is based on the proportions of alkali and alkaline earth metals (sodium, potassium, magnesium and calcium) present. Chemical Index of Weathering (CIW) was developed by Harnois in 1988 [22]. This index is defined as a measure of the extent of conversion of feldspars to clays. It has the same formulation as CIA except that it eliminates K₂O. Because plagioclase is abundant in silicate rocks and dissolves rapidly [21], Plagioclase Index of Alteration (PIA) was developed in 1995 by Fedo et.al to fill the gap. To correlate chemical weathering of metamorphic silicate rocks in tropical regions, Silica-Titania Index (STI) was devised by Jayawardena and Izawa, 1994. According to the research, the STI correlated well with the Ruxton Ratio (RR). Summary of weathering indices evaluated in this study is shown in Table 1.

In an effort to determine rock material properties of schist of Menderes Massive, rock samples were collected from the rock quarries of the dams. In the study, water content of schist was used to determine weathering of schist.

Simple random sampling was done in the study area from fresh schist (F), slightly weathered (SW), moderately weathered (MW) and highly weathered (HW) schist.

Petrographic and chemical properties for the schist were determined and combined with their index and material properties. All the relationships were determined by using simple regression analyses. Generally, It is expected that weathering increases if certain major oxides (Al₂O₃, Fe₂O₃ and TiO₂) remain constant while SiO₂, Na₂O, K₂O, CaO and MgO decrease and LOI increases [27, 28].
Wide standard deviation range in some geotechnical parameters is common for anisotropic rocks such as schist [29]. While uniaxial compressive strength (UCS) of muscovite quartz schist is between 93 ± 15 MPa and 32 ±8.56 MPa [29]. Due to that reason perpendicular loading to the anisotropy was preferred in our tests. All the good correlations between the various mechanical properties and weathering grades are described for the different types of schist.

2. Material and Methods

After the 1/1000 scaled mapping of dam/small dams which were planned to be built, the samples from the rock quarries were taken to determine their mineralogical, physical and mechanical features. The sampled sites are depicted in (Figure 2).

2.1 Petrographic Studies

The sequence of the Massif continued until Paleocene prior to being subjected to the Main-Metamorphism, which has given the present aged Menderes Massif green-schist facies and blue-schist facies [7, 32]. A total of 29 rock samples were tested for the project. The petrographic features of rock materials were analyzed at Dokuz Eylül University- Geology Engineering Department- Mineralogy and Petrographic Laboratory and at the State of Hydraulic Works in Technical Research and Quality Control Department- Mineralogy and Petrographic Laboratory position of the Menderes Massif related to the thrusting of the Lycian nappe comlex between Paleocene-Late Eocene time. This metamorphism which took place under the medium pressure/high temperature conditions, accounts for the formation of the Borrowian-Type mineral assemblages [7]. The study areas are located in the Precambrian.

According to the thin-section analysis presented in Figure 3, the main mineralogical composition of the schist located in the rock material quarry of Burgaz dam is Calcschist; in the quarry run and fun rockfill material of Arslanlar small dam are Biotite Musquoviteschist with Garnet and Musquovite Quartzschist respectively and in the rock material quarry of Yenişehir small dam is Garnet BiotiteSchist (Table 2). In the body dams the less weathered schists used appeared effective.

3.2 Geochemical Analysis

Major element compositions of the samples taken from studied dam rock material quarries were determined by X-ray fluorescence (XRF) via TS EN 15309 standards in the XRF laboratory in the Dokuz Eylül University Geology Engineering Department. A data set of 29 analyses of schist rocks was obtained, with representative analyses presented in Table 3. Silica contents of the observed samples are between 62.15% - 93.15%, while Al$_2$O$_3$ contents are generally between 3.10% - 18.78 wt.%, indicative of weathering precursors.
The amounts of CaO, K₂O and Na₂O decrease during the early stages of weathering for studied rocks. It was observed that LOI increases with increasing clay minerals introduced by the weathering of feldspar, mica and the other silica minerals. LOI appears to be a good indicator of chemical weathering. Generally, as LOI increases, the weathering degree increases [30, 16].

Using the relationship between major elements and LOI of Calcschist, Muscoviteschist, Quartzschist and Biotiteschist the weathering rate was determined based on the formulas of various indices in Table 1. The results are compared with LOI value of studied schist and the simple regression graphics are shown in Figure 4. PIA and RR indices were applied to determine the weathering index. From Figure 5 it can be observed that, the relationship between RR index and LOI is quite significant, with the best correlation coefficient \( r = 0.91 \). Based on Figure 4, LOI of Quartzschist of Arslanlar fun rock material quarry ranges between 0.60-0.91. The LOI appears to increase with the increasing Al₂O₃ wt%.

This can be explained by the fact that LOI is related to secondary mineral formation such as clay minerals formed by the weathered of feldspar, mica and the other weathered alumina silicate.

To determine weathering grade of studied schist water content of the samples was used. At the studied areas, samples of fresh schist could not be found. As such, water content for slightly weathered quartzschists in the Arslanlar fun rock material quarry, was used as a representative for water content of fresh-rock. The weathering degree is calculated by using the difference in amount of water content between the weathered and the fresh rock after [31].

\[
D_w = \frac{(W_w - W_o)}{W_o}
\]

Where,
\( D_w \) = Weathering grade
\( W_w \) = Water content of weathered rock (%)
\( W_o \) = Water content of fresh rock (%).
The criteria for interpreting the weathering grades of rocks are defined as,

| Dw  | Weathering Grade |
|-----|------------------|
| 0   | Fresh (W1)       |
| 0-4 | Slightly weathered (W2) |
| 4-8 | Moderately weathered (W3) |
| 8-12| Highly weathered (W4) |
| >12 | Completely weathered (W5) |

According to the relationship between water content of the tested samples and weathering grade, Quartzschist, taken from Arslanlar small dam – fun rock material quarry, can be described as fresh rocks (W1) in the Menderes Massive. Due to high water content, Musquoviteschist-from Arslanlar small dam-run rock material quarry, and Calcschist-from Burgaz dam-rock material quarry may be evaluated as moderately weathered (W3) schist, while Biotiteschist-from Yenisehir small dam- rock material quarry is highly weathered schist (W4) (Table 4).

3.3 Physical and mechanical properties

Samples taken from study areas were tested at the DSI-Rock Material Laboratory and Dokuz Eylül University- Department of Geology Engineering-Rock and Soil Laboratory to determine physical and mechanical properties. The obtained results of the tests are presented in Table 5.

From the test results, regression analyses between mean value of LOI, which is indicator of the weathering grade in the rock, and mechanical and physical parameters of the tested schists were performed and the relationships are presented in Table 6 and All the analyses gave positive correlation results with high coefficient of determination (r).

According to these results, it can be extrapolated that the physical and mechanical properties of the studied schist show a valuable relationship with weathering grade. As it is clear that, increasing weathering grade affects the durability of the schist.

4.0 Conclusions

The weathering characteristics of schists in Menderes Massif were evaluated by chemical and petrographic analyses and physical and mechanical test. Weathering grades of the selected schist were described by using of water content and the weathering descriptions were checked by chemical and petrographical weathering indices to establish the schist suitability of application. Statistical analyses showed that, the relationship between RR index and LOI gave the best correlation with the highest coefficient r= 0.91.

The results also showed that all of physical and mechanical properties of the studied schist have a positive correction with weathering grade. Thus, increasing weathering grade affects the durability of the schist. Corollary, the applicability of the rock materials get compromised. From the study, we
recommend a thorough priori test of the schist when it has been considered to be used as a filler material in the dams/small dams.

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