DOI: 10.4408/IJEGE.2011-03.B-010

FORMATION MECHANISMS OF DEBRIS-FLOW MATERIAL ON SLOPES INROUDBAR-E-GHASRAN, IRAN; A CASE STUDY OF THE WEATHERING IMPACTS

Mojgan Hadi MOSLEH(*) & Farzan RAFIA(**)

(*) Geoenvironmental Research Centre, Cardiff University, Cardiff, UK Former Postgraduate Student, Bu-Ali Sina University, Hamedan, Iran
(**) Kavoshgaran Consulting Engineers Company, Tehran, Iran

ABSTRACT

Debris flows are widespread in many steep slopes in northeastern of Tehran province, Iran. The slopes in that region are mostly covered by a relatively thick mantle of weathered debris. Parent rocks mainly consist of vitric tuff and tuffaceous limestone of middle Eocene age. Several factors such as geomorphology, structural geology, tectonics and weathering as well as construction works trigger instability of slop in that area. Among various factors on the formation of debris-flow material, tectonics and weathering have been found to be the most influential factors.

This study is focused on the formation mechanisms of debris-flow material and weathering indices of the parent rocks. The effects of weathering on some slopes in the first 15 km of the main road from Zardband to Meygoon were studied. Soil and rock samples were collected from the currently stable slopes as well as material from an old landslide. Geotechnical properties of the debris mantle were investigated using a series of field and laboratory tests. In addition, different weathering indices comprising of petrographical, engineering and chemical tests have been conducted in order to assess the most dominant type of weathering. Finally, it was concluded that mechanical weathering is the most influential process in the formation of talus material in the study area.

***Key words**: debris flow, weathering, weathering index, tuff*

INTRODUCTION

Physical and chemical properties of soft sedimentary rocks can be highly affected by weathering process resulting in the alteration of the engineering behaviour of debris-flow materials, deposited on the slopes. Characterisation of the weathering process of parent rocks in debris-flow material is a crucial issue in assessing the stability of slopes that are covered with debris-flow materials (Yakota & Iwamatsu, 1999). The weathering process generally is defined as the breakdown of solid bedrock, through different mechanisms such as chemical, biological, and mechanical process, as well as complete transition between bedrock and soil. Among all weathering mechanisms chemical and mechanical effects are the most dominant factors in breaking down the rocks into fragments (Timothy, 2008).

This paper aims to investigate the important weathering indices including petrographical, chemical and engineering indices and a discussion of their limitations and usefulness with regard to climate condition. Some of the existing methods for determination of weathering indices have been tested in experiments on two common rocks of the Eocene Karaj formation: gray-green vitric tuff and dark gray tuffaceous limestone. The results are discussed and the most dominant type of weathering in the region is discussed in the conclusion section.

LOCATION AND GEOLOGY

The investigated area in this paper is located in the northeastern part of Tehran province in Iran, along

Fig. 1 - Location of the investigated area

Fig. 2 - Location of the existing landslides in Roudbar-e-Ghasran region (Mountains view from Google earth, 2010)

15 km of the main road which connects Zardband village to Fasham city (Fig. 1).

The region is located in the high mountainous area of Roudbare- Ghasran with altitude ranging between 2500 and 4000 m. Based on the recorded data in the Landslide Database of Iran (2007), several old landslides and debris-flows have occurred during the last hundred years in this region. In the last ten years, the number of reported landslides has increased considerably, reported to be related mainly to the urban development and road widening (Landslide Database of Iran, 2007). Figure 2 shows some of the existing landslides in the study area. Accordingly, the location of recent landslides is mostly in the vicinity of the main roads

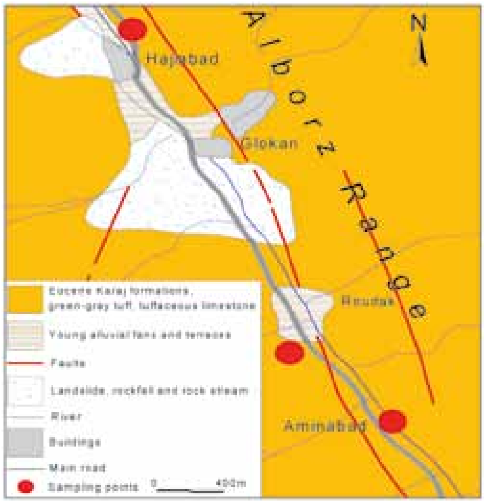

Fig. 3 - Geological map and location of the study area (NGDIR, 2006)

or close to the urban development activities whilst old landslides are located almost far from the main roads.

From geological point of view, the widest tectonostratigraphic units are Eocene pyroclastic and volcanoclastic sequences (Karaj formation) covering a wide region on the southern slopes of the Alborz Range (Figure 3).

The Eocene Karaj Formation is exposed in most parts of the south central Alborz Range, bounded by major thrust faults. This formation is a volcanic-sedimentary unit that consists of a variety of tuffs. Based on petrographical studies the tuffs in this region are mainly classified into three main categories including crystalline, vitric, and lithic tuffs (NGDIR, 2006). The lithic tuffs contain more sedimentary components and mainly include shale and siltstone- sandstone tuffs with gray to dark gray color (Yassaghi *et alii*, 2005). Massive parts of volcanic tuffs in the study area mainly consists of green-gray vitric tuff and dark gray tuffaceous limestone.

Slopes in the region are mostly covered by relatively thick fragmented materials and talus. The origin of these materials is mainly Karaj formation. Tectonics and weathering are known as two major factors responsible for formation of these materials in the region. The effects of tectonics and fault activities in the formation of talus in the study area have been studied and reported in the literature (e.g., Tchalenko *et alii*, 2007; Nasiri, 2004; Ambraseys & Melville, 1982). In this paper, the effects of weathering on formation of talus material are investigated and the most influential types of weathering in the region also are discussed.

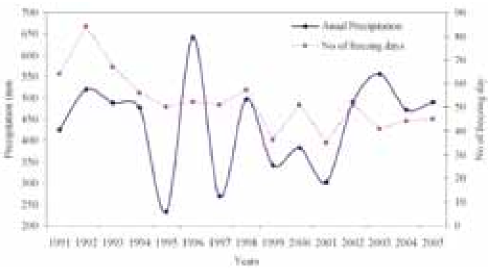

Fig. 4 - Average precipitation between 1990 and 2005 and the number of days with a minimum temperature equal to 0°C and below

Fig. 5 - Debris material on a steep slope near to Aminabad village

CLIMATE CONDITION

According to the Köppen climate classification (Peel *et alii* 2007), northeastern Tehran has a cold semi-arid climate whilst the weather is often cooler in the hilly areas of the north as compared to the flat southern part of Tehran. Based on the collected data by the Iran Meteorological Organization, the average annual precipitation is between 500 to 570 mm and the average annual temperature is about 12°C. The hottest month in the region is July with a mean minimum temperature of 22°C and a mean maximum temperature of 34°C. The coldest month is January with a mean minimum temperature of -1°C and a mean maximum temperature of 7°C (IRIMO, 2006). Figure 4 shows the meteorological records of the north Tehran station between 1990 and 2005.

FIELD AND LABORATORY INVESTIGATIONS

In order to investigate the factors that affect the weathering of parent rocks, samples were collected from different locations where slopes are covered by relatively thick layers of talus materials. Two types of tuffs were found dominantly as the parent rocks of the debris materials on the selected slopes including vitric tuff and tuffaceous limestone. Existing data from occurred landslides in the study area suggest that the origin of debris material is Karaj formation.

Figure 5 shows one of the sampling points near Aminabad village. Field and laboratory experimental studies were carried out on collected samples of the selected slopes. The selection of experimental studies was mainly based on the determination of weathering indices. Microscopic thin-sections were prepared for petrological studies; the X-Ray Fluorescence (XRF) test was performed on rock samples for chemical characteristics purposes; tests such as point load test, and the Schmidt rebound hammer test were carried out as well as laboratory tests including physical properties, slake durability, wetting-drying, freezing-thawing and soundness tests.

PHYSICAL PROPERTIES OF PARENT ROCKS (INTACT ROCK)

Physical indices such as specific gravity, dry and saturated densities, porosity and void ratio were determined for the rock types following the standard test procedures suggested by ISRM (1981). Schmidt Rebound hammer test also was carried out according to standards in ISRM (1993). The uniaxial compressive strength for the two rock types was determined based on Point load test on 20 irregular lumps and 10 cylinder shape samples. Physical properties of the studied parent rocks are presented in Table 1.

The point load test index shows that compressive strength of tuffaceous limestone is two times larger than vitric tuff. Accordingly, tuffaceous limestone and vitric tuff were classified as class A (Very high strength) and class B (High strength) rocks, respectively (Deere & Miller, 1966).

SLAKE DURABILITY TEST

The slake durability test is regarded as an initial assessment of the weatherability of rocks. This test is intended to assess the resistance of rock samples to fragmentation (Franklin & Chandra, 1972). Rock samples were put into an apparatus that comprises two sets of drums and were rotated in water that had a level of about 20 mm below the drum axis. After slaking for the period of 10 minutes, samples were dried in an oven at a temperature of 105°C for up to 6 hours. The test was conducted over two cycles, the weight loss of particles of 10

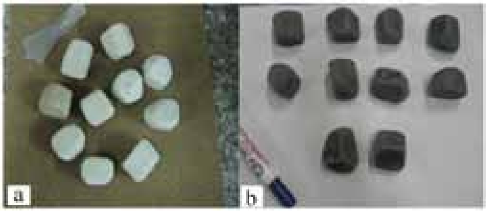

Fig. 6 - Slake durability test and samples condition after second cycle. a) Vitric tuff, b) Tuffaceous limestone

rock lumps retained in these wet-dry cycling tests were determined (Fig. 6).

The slake durability index (Id_2) of vitric tuff and tuffaceous limestone were 99.86% and 99.92%, respectively. Both rock types seem to have high resistance in the slake durability test as the index of durability tends to more than 90%. Rocks are ranked as class 6 or extremely high strength according to Sadisun *et alii* (2002).

Parameters	Unit	Vitric Tuff	Tuffaceous Limestone
Dry density (γd)	kN/m^3	23.61	29.64
Water content (w)	%	0.22	0.03
Porosity (n)	%	8.69	0.51
Point load test index (Is50)	MPa	6.73	11.82
Schmidt Rebound hammer value (N)	-	48	50
Uniaxial compressive strength (UCS)	MPa	144.00	149.00
Slake durability index (Id2)	%	99.86	99.92
Wetting-drying loss	%	0.1	0.2
Freezing-thawing loss	%	4.07	0.47
Soundness loss	%	3.65	0.19

Tab. 1 - Physical and engineering properties of parent rocks

WETTING- DRYING AND FREEZING AND THAWING TESTS Wetting-drying and particularly freezing-thawing processes are significant atmospheric events causing physical disintegration of rock materials in a long time. Fookes *et alii* (1988) mentioned that crystallization processes such as freezing-thawing can be deleterious to rock materials over short periods of time. A 9% volumetric expansion upon phase change of water is known as the major reason of rock breakdown (Ollier, 1984).

The effect of these processes was quantified by performing wetting-drying and freezing-thawing tests on two major rock types of the region according to the Sadisun *et alii* (2002) and ASTM D5312. The results are represented in Table 1.

SOUNDNESS

In the Soundness test, samples are exposed to cycles of wettingdrying by a sulphate solution. After each drying cycle, the dehydrated sodium or magnesium sulphate precipitated in pore spaces of aggregates causes expansion during the soaking cycle. This expansion simulates the expansion of water upon freezing (Forster, 1994).

In order to determine the type of sulphate solution (sodium or magnesium sulphate), natural water in the study area was collected and analysed in Analytical Chemistry laboratory at Bu-Ali Sina University. The amount of sodium and magnesium in natural water was 44.90 ppm and 1.99 ppm, respectively. Therefore, the Soundness test was carried out using saturated solution of sodium sulphate according to ASTM STP 169C (Forster, 1994). The results of soundness test are presented in Table 1.

RESULT AND DISCUSSION

The climatic conditions have an important effect on weathering processes of rock materials, in addition to the other environmental factors such as hydrosphere and topographical conditions. The relationship between mean annual temperature and mean annual rainfall can be used to describe the regional importance of mechanical weathering (Peltier, 1950). Figure 4 shows the number of wetting-drying and freezing-thawing cycles which describes the importance of climatic condition in a period of 15 years. A close relationship between climate conditions and weathering rate of rocks has been well established (e.g., Weinert, 1964; Sanders & Fookes, 1970).

Every year, the study region is covered by snow for a period of 4 to 5 months. While rainfall is dominant during spring, hot and dry weather conditions are generally observed during the summer. Therefore, when seasons are considered altogether, it is apparent that physical weathering processes (i.e., freezing-thawing) may control the fragmentation of bedrocks. Changing the water phase might cause a 9% volumetric expansion resulting in 200 MPa pressure which is caused by freezing process (Ollier, 1984). The stress may exceed the tensile strength of rocks several times within a year.

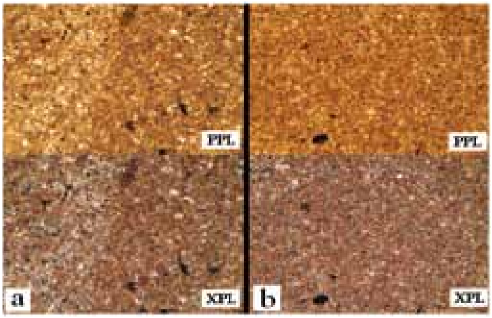

Fig. 7 - Microscopic thin section under XPL and PPL (magnification: 250×.) a) tuffaceous limestone, b) vitric tuff

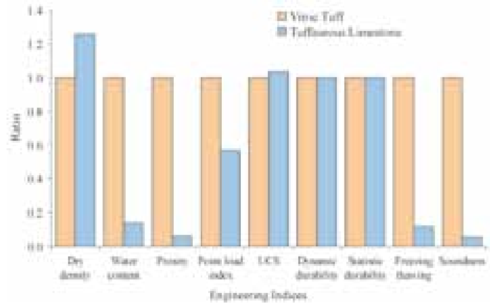

Fig. 8 - Engineering indices and weathering ratio of parent rocks

Considering only the temperature variations around 0°C in Figure 4, there were at least 15 freezing-thawing cycles between 1990 to 2005. Although, within each year, there were a number of times the temperature variations around 0°C produced freezing- thawing cycles (IRIMO, 2006). However, the availability of water for this physical process is very important. Therefore, in determination of the physical processes, the precipitation needs to be used as an input parameter in freezing-thawing cycle determination as well as temperature variations.

In order to quantify the effect of climate condition on green-gray tuffs and dark gray tuffaceous limestones, weathering indices were investigated. Weathering indices are widely used in studies of both modern and ancient in situ weathering profiles, demonstrating the impact of climate on bedrock weathering (e.g., NEALL, 1977). The most commonly used methods for weathering indices can be categorized as mineralogical-petrographical, engineering, and chemical indices (GUPTA & SESHAGIRI, 2001). The common weathering indices are discussed below with regard to their applicability for the assessment of the weathering effects on different bedrock in the study area.

MINERALOGICAL/PETROGRAPHICAL INDICES

The number of micro-fractures is considered as petrographical index (DIXON, 1969) by making a squared traverse using the point counting method. In order to investigate the effect of petrographical index on weathering of bedrocks, 13 thin sections were prepared and studied with a polarizing petrographic microscope. Figure 7 shows one of the microscopic images. As shown in Figure 7, microstructures are not developed in the fabric of both rock types, therefore petrographycal index can not be used as a factor of weathering evaluation in this study area.

ENGINEERING INDICES

The physical characterisation of the bedrock was determined based on several index properties such as dry specific weight, porosity, saturated moisture content, and compressive strength. All samples used in physical characterization tests were prepared according to the ISRM (2007) suggested methods (Table 1). Figure 8 indicates the histogram of engineering indices as comparative values. Both rock types have similar static and dynamic durability indices, but there is a considerable difference between Freezingthawing index and Soundness index of both rocks (e.g., vitric tuff and tuffaceous limestone).

CHEMICAL INDICES

Chemical weathering indices, sometimes referred to as indices of alteration, are commonly used for characterizing weathering profiles. Chemical weathering indices incorporate bulk major element oxide chemistry into a single value for each sample.

Chemical indices studied for the weathering of tuffaceous limestone and vitric tuff are represented in Table 2. According to the results represented in Table 2, Alkaline Ratio and Chemical Index of Alteration show that vitric tuffs have more weathering potential than tuffaceous limestone. Product index and Silica-Titanium Index are similar in both rock types. Finally, only SAR represents higher rate of weathering in tuffaceous limestone than vitric tuff.

Although the indices based on chemical and petrographical characteristics can explain the variations in the basic characteristics of rock material caused by weathering (such as chemical alteration, fabric and mineralogical changes), their evaluation is experimentally difficult. However, a weathering index based on engineering properties is preferred over other kind

Chemical Indices	Chemical equation	Vitric Tuff	Tuffaceous Limestone	References
Silica–Alimina Ratio	$SAR = (SiO_2)/(Al_2O_3)$	4.9	5.8	Ruxton, 1968
Product Index	$PI = SiO_2 \times 100 / (SiO_2 + TiO_2 + Fe_2O_3 + FeO + Al_2O_3)$	80.8	80.7	Reiche, 1943
Parker index	$Wp = [2\ Na_2O / 0.35] + [MgO / 0.9] + [2\ K_2O / 0.25] + [CaO / 0.7]$	87.8	77.8	Parker, 1970
Silica-Titania Index	$Si\text{-}Ti = [SiO_2 / TiO_2] / [SiO_2 / TiO_2 + SiO_2 / Al_2O_3 + Al_2O_3 / TiO_2]$	0.8	0.8	Jayaverdena & Izawa, 1994
Alkaline Ratio	Alkaline Ratio= $(K_2O \times 100) / (K_2O+Na_2O)$	85.1	92.4	Harrois and Moore, 1988
Chemical Index of Alteration	$CIA= (100 \times Al_2O_3)/ (Al_2O_3 + CaO + Na_2O + K_2O)$	51.2	23.1	Nesbitt & Young, 1982

Tab. 2 - Chemical indices of parent rocks

of indices, considering that the criteria used can be easily and quickly determined in the field as well as in the laboratory. The ability to predict the engineering performance of weathered rock is also important for geotechnical purposes (Gupta & Seshagiri, 2001).

CONCLUSION

The most dominant type of weathering in the region is defined according to climatic condition and an N-value (Weinert, 1980). The N-value provides an indication of the dominant mode of weathering of rock material. The N-value is based on the following formula:

$$N = 12E_j / P_a$$

where N is climatic index or N-value, E_j is evaporation amount during the warmest year in the region, and P_a is the total annual precipitation both in mm. In arid areas, the N-value is more than 5 and mechanical fragmentation of rock is predominant. In humid areas, the N-value is less than 5 and chemical decomposition of rock occurs (Weinert, 1980). From the meteorological records of the study area, E_j and P_a are 2374 mm and 421 mm, respectively. Therefore, the N-value for this region is 5.64 indicating that mechanical disintegration is the dominant mode of weathering in the region.

Because, the Soundness test simulates the expansion of water during a freezing process, the result of this test also supports the dominance of physical weathering (the weight loss of green-gray tuffs is significant).

In conclusion, the results of this investigation indicates that mechanical weathering is the most influential process in breakdown of parent rocks of Karaj green-gray tuffs and formation of talus material on the slopes in northeastern Tehran province. In addition, based on the results of freezing-thawing and Soundness tests, about four percents of vitric tuffs break down into the small fragments in every five freezing-thawing cycles. Hence, talus production rate in the study area is estimated to be considerable and effective on the formation and instability potential.

ACKNOWLEDGEMENTS

This research was part of MSc thesis of first author at Bu-Ali Sina University. The first author would like to acknowledge the support of all academic staffs and the supervisory team as well as Kavoshgaran Consulting Engineers.

REFERENCES

Ambraseys N.N. & Melville C.P. (1982) - *A history of Persian earthquakes.* The Press Syndicate of the University of Cambridge.

ASTM. (1992) - *American society for testing and materials, anual book of ASTM standards*. 4, Philadelphia.

Ceryan S. (2008) - *New chemical weathering indices for estimating the mechanical properties of rocks: A case study from the Kürtün Granodiorite, NE Turkey*. Turkish Journal of Earth Sciences, **17**: 187-207.

Deere D.U. & Miller R.P. (1966) - *Engineering classification and index properties for intact rock.* Air Force Weapons Laboratory Technical Report AFWL-TR-65-116.

Delvaix B. Herbillon A.J. & Vielvoye L. (1989) - *Characterization of a weathering sequence of soils derived from volcanic ash in Cameroon. Taxonomic, mineralogical and agronomic implications*, Geoderma, **45**: 375-388.

Dixon H.W. (1969) - *Decomposition products of rock substances: proposed engineering geological classification*. In: Proc. Symp. on Rock Mech., Sydney University, 39-44.

Duzgoran-Aydin N.S., Aydin A., & Malpas J. (2002) - *Re-assessment of chemical weathering indices case study on Pyroclastic*

Rock of Honk Kong. Journal of Engineering Geology, **63**: 99-119.

Duzgoren-Aydin N.S. & Aydin A. (2003) - *Chemical heterogeneities of weathered ignous profiles: implications for chemical indices.* Environmental and Engineering Geoscience, **9**: 363-376.

Fookes P.G., Gourley C.S. & Ohikere C. (1988) - *Rock weathering in engineering time*. Quarterly Journal of Engineering Geology, **21**: 33-57.

Forster S.W. (1994) - *Chapter 36: Soundness, Deleterious Substances, and Coatings.* ASTM Special Technical Publication, STP 169C: Significance of Tests and Properties of Concrete and Concrete-Making Materials, 411-420.

Franklin J.A. & Chandra R. (1972) - *The slake durability Test*. International Journal of Rock Mechanics and Mining Science, **9**: 325-341.

Google Earth (2010) - Version 5.1.3533.1731[Software]. Mountain View, CA: Google Inc., Available from *www.google.com/earth/index.html*

Gupta A.S. & Seshagiri K.R. (2001) - *Weathering indices and their applicability for crystalline rocks*. Bulletin of Engineering Geology and Environment, **60**: 201-221.

Harrois L. & Moore J.M. (1988) - *Geochemistry and origin of the ore chimney formation, a transported paleoregolith in the Greenville province of souteastern Ontario, Canada.* Chem. Geol., **69**: 267-289.

IRIMO (2006) - Republic of Iran metorological organization, *www.irimet.net* Islamic.

ISRM (1981) - *Rock characterization, testing and monitoring*. In: Brown E.T. (Eds.) *Suggested mothods*. Pergamon Press, Oxford.

ISRM (1993) - *Supporting paper on a suggested improvement to the Schmidt rebound hardness.* ISPNO. Particular Reference to Rock Mach. Ability.

ISRM (2007) - *The complete ISRM suggested methods for rock characterization, testing and monitoring: 1974-2006.* In: Ulusay R. & Hudson J.A. (Eds.), *Suggested methods prepared by the commission on testing methods*. International society for rock mechanics, Ankara, Turkey.

Jayaverdena U. de S. & Izawa E. (1994) - *A new chemical index of weathering for metamorphic silicate rocks in tropical regions: a study from Sri Lanka*. Engineering Geology, **36**: 303-310.

Kusky T.M. (2008) - *Landslides: Mass Wasting, Soil, and Mineral Hazards, Facts on File,* The Hazardous Earth. ISBN-13: 9780816064656.

Landslide Database of Iran (2007) - *Forests, Range and Watershed Management Organisation*, Tehran, Iran.

Nasiri S. (2004) - *Mapping of landslides caused by earthquake in north Tehran.* The MSc thesis, Tarbiat Modares University, Tehran, Iran, (in Persian).

Neall V.E. (1977) - *Genesis and weathering of andosols in Taranaki, New Zealand.* Soil Science, **123**: 400-408.

Nesbitt H.W. & Young G.M. (1982) - *Early proterozoic climates and plate motions inferred from major element chemistry of Lutites.* Nature, **299**: 715-717.

NGDIR (2006) - National geoscience database of Iran, *www.ngdir.ir*

Ollier C. (1984) - *Weathering geomorphology texts. 2nd ed.*, Oliver & Boyd, Edinburg.

Peel M.C., Finlayson B.L. & McMahon T.A. (2007) - *Updated world map of the Köppen-Geiger climate classification.* Hydrol. Earth Syst. Sci., **11**: 1633-1644.

Peltier L.C. (1950) - T*he geographic cycle in periglacial regions.* Annals of the Association of American Geographers, **40**: 214-236.

Parker A. (1970) - *An index of weathering for silicate rocks*. Geol Mag., **107**: 501-504.

Reiche P. (1943) - *Graphic representation of chemical weathering*. Journal of Sediment Petrol., **13**: 58-68.

Ruxton B.P. (1968) - *Measures of the degree of chemical weathering of rocks*. Journal of Geol., **76**: 518-527.

Sadisun I.A., Shimada H., Ichinose M. & Matsui K. (2002) - *Evaluation of physical deterioration of slake-prone rock subjected to static slaking test*. The 11th Japan National Symposium for Rock Mechanics, Chiba, Japan, Paper No. **E-01**.

Sanders M.K. & Fookes P.G. (1970) - *A review of the relationship of rock weathering and climate and its significance to foundation engineering*. Engineering Geology, **4**: 289-325.

Sharma A. & Rajamani V. (2000) - *Major element, REE, and other trace element behavior in amphibolite weathering under semi-arid conditions in southern India*. Journal of Geology, **108**: 487-496.

Tchalenko J.S., Ambraseys N.N., Berberian M., Iranmanesh M.H., Mohajer-Ashjai A., Bailly M. & Arsovsky M. (2007) -

Materials for the study of seismotectonics of Iran. Geological survey of Iran.

UNESCO (1993) - *A suggested method for describing the activity of a landslide. Working party on world landslide inventory*, Bulletin of the International Association Engineering Geology. **47**: 53-57.

Weinert H.H. (1964) - *Basic igneous rocks in road foundations.* CSIR Research Report 218. Bulletin of the National Institute of Road Research, Preterio.

Weinert H.H. (1980) - *The natural road construction materials of southern Africa*. Academica, Pretoria.

Yakota S. & Iwamatsu A. (1999) - *Weathering distribution in a steep slope of soft pyroclastic rocks as an indicator of slope instability.* Engineering Geology, **55**: 57-68.

Yassaghi A., Salari-Rad H. & Kanani-Moghadam H. (2005) - *Geomechanical evaluations of Karaj tuffs for rock tunneling in Tehran-Shomal freeway, Iran.* Journal of Engineering Geology, **77**: 83-98.