

Geotechnical characteristics of granular pumice soils in Nevşehir region

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ABSTRACT: The geotechnical characteristics of the pumice soils existing inside the residential areas of Nevşehir City were investigated in this study. In that region, the granular material encountered in natural deposits is named as “pumice” which is softer and has lower density and higher void ratio than those of natural sands. In general, pumice aggregates are formed during a series of volcanic explosions and they involve vesicles and numerous macro/micro scale voids due to their sudden cooling after the gases inside the aggregates have suddenly escaped from their bodies. Today, the deep and shallow pumice deposit layers exist at volcanic regions, flood plains and river valleys as sand-gravel deposits. Three different working areas where granular pumice layers exist were selected at Nevşehir City Center. In order to determine the geotechnical characteristics of pumice, there were carried out sieve analysis, specific gravity, dry unit weight, water absorption ratio, water submergence and shear box tests. Additionally, mercury porosimeter test, SEM analysis and chemical analysis were also performed on pumice. When the pumice soils were evaluated by considering the geotechnical viewpoint, they differed from silica sands in terms of physical and engineering characteristics. As a conclusion, it was observed that the specific gravity, dry unit weight, water absorption ratio and angle of internal friction of granular pumice soils increased as a result of decreasing grain size of granular pumice aggregates.

1 INTRODUCTION

Pumice is found as a granular and clast material in nature. Granular pumice deposits exist in many parts of the world and Turkey. This type of soils is formed as a result of a series of volcanic explosions that cause the pumice material to be distributed into a wide area by the aid of wind and river effects.

The pumice material has been distributed initially by the explosive power of the eruptions and associated airborne transport; this has been followed by erosion and river transport. Pumice deposits exist mainly as deep sand layers in river valleys and flood plains, but are also found as coarse gravel deposits in hilly areas. Interest in these materials stems from the softness of the grains compared to more usual sands, the low densities and the high void ratios (Pender et al. 2006).

The pumice deposits are characterized by the vesicular nature of their particles; each particle contains a dense network of fine holes, some of which may be interconnected and open to the

surface, while others may be entirely isolated inside the particles (Wesley, 2001). While Figure 1 shows a pumice particle, Figure 2 presents a schematic representation of pumice particles.

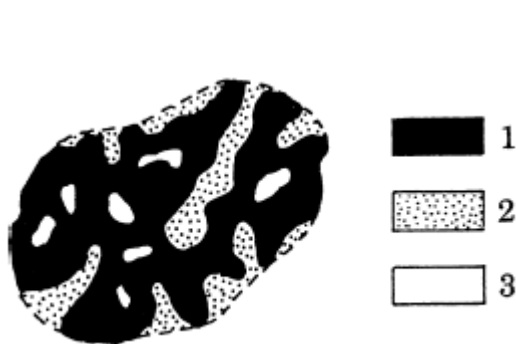


Figure 1. Voids within a pumice clast (Pellegrino, 1966)
1. Solid material 2. External voids 3. Internal voids



Figure 2. Schematic representation of pumice particles (Wesley, 2001).

With conventional materials the estimation of void ratio is straightforward; the specific gravity of the soil particles is measured and the volume they occupy thus determined. With pumice sand, however, the situation is no longer straightforward, due to the vesicular nature of the particles. This vesicular nature means that there are both interparticle voids and intraparticle voids (Esposito & Guadagno, 1998). This situation creates difficulties about the void ratio and the soil porosity calculation of pumice. At stresses greater than a few hundred kPa, the stress-strain-strength behaviour of these soils is dominated by particle crushing. Grains of pumice sand may be readily crushed against a hard surface by fingernail pressure (Pender et al. 2006).

In this study, the geotechnical properties of pumice soils remaining within the boundaries of the province of Nevsehir in three different areas were investigated (Soğancı, 2011). The working area-2 given in Figure 3, has the soil profile given in Figure 4. The working area has been located in an urban area that granular pumice layers can be observed in the excavation area of the current construction site. Also most of the construction foundations were settled on this layer.



Figure 3. Working area-2

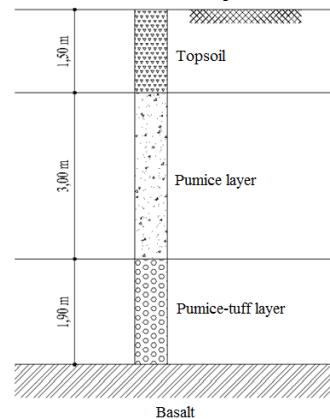


Figure 4. Soil profile for working area

2 EXPERIMENTAL STUDY AND RESULTS

In the experimental study, the sieve analysis, specific gravity, dry unit weight, determination of water absorption ratio, sinking test in water and shear box tests were conducted to determine the geotechnical properties of pumice. Additionally, the mercury porosimetry experiments, SEM analysis, chemical analysis were performed on pumice. Some of these studies were executed in the laboratories of the Civil Engineering Department of Selcuk University Engineering & Architectural Faculty while the others were carried out in different institutions.

2.1 Sieve Analysis

The sieve analysis was made as specified in ASTM C136-06 to determine the particle-size distribution. The results of sieve analysis performed on three study areas were given in Figure 5 where the results can be observed too much closer to each other. Looking at the average values of the granulometric curves, they are 44% and 56% for gravel-sized pumice and sand-sized pumice, respectively. $D_{60} = 5.2$, $D_{30} = 2.8$, $D_{10} = 1.7$, $C_u = 3.06$ and $C_c = 0.89$ were also obtained. According to these values, the pumice soil takes place in SW classification in Unified Soil Classification System.

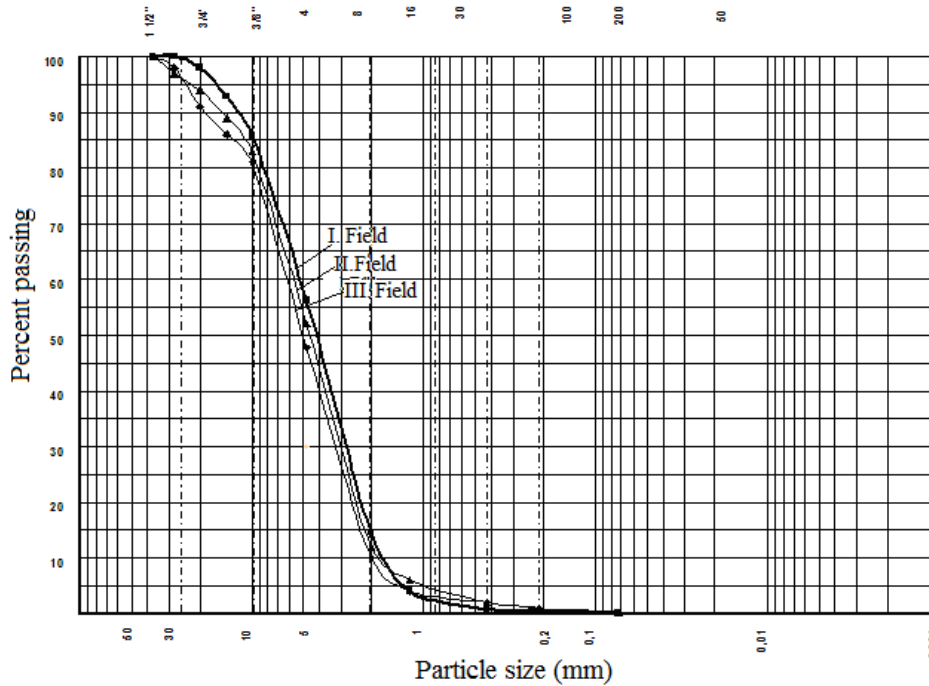


Figure 5. Particle-size distribution curve for granular pumice samples

2.2 Determination of Specific Gravity

The specific gravity tests were carried out in three ways. Firstly, a simple displacement technique was used; a known dry weight of the material was poured into a measuring cylinder containing water and the rise in water level was measured. It was expected that this procedure would minimize the entry of water into the internal voids of the particles. Secondly, a calibrated pycnometer was used, following the normal procedure, but without any vacuum air extraction. It was found that these two methods gave virtually identical results. The specific gravity so obtained will be referred to as the “direct” or “displacement” value (G_D). Finally, measurements were made using the standard procedure with a pycnometer and vacuum extraction of air, which is called as ASTM 854-10 standard procedure. The values obtained in this way will be referred to as the “standard” values (G_S). For the 1st working-area, the results of specific gravity test with pycnometer by direct value without vacuum extraction and standard value using vacuum extraction are given in Table 1 for different pumice particle sizes.

Table 1. Specific gravity values obtained by direct value without vacuum extraction and standard value using vacuum extraction

Particle size (mm)	Direct Value without Vacuum Extraction (G_D)	Standart Value using Vacuum Extraction (G_S)
9.51 – 19	0.91	1.82
4.76 - 9.51	0.99	1.84
2 – 4.76	1.50	1.87
1 – 2.00	1.75	1.91
0.5 – 1.00	1.87	1.96

2.3 Determination of Dry Unit Weight

The dry unit weight of pumice was determined according the procedure ASTM C 29. In the experiment, a measuring cup of 250mm diameter , 280 mm height and 3.5 mm thickness was used. The pumice samples of different diameters were placed spreading all over the surface with a rodding bar after squeezing with 25 hits. The results of dry unit weight, specific gravity, porosity and void ratio for pumice samples prepared with different diameters are given in Table 2.

Table 2. The results of dry unit weight, specific gravity, porosity and void ratio for pumice samples prepared with different diameters

Sieve gap (No)	Sieve diameter (mm)	Dry unit weight kN/m^3	Specific gravity (Standard procedure)	n	e
3/8" – 3/4"	9.51 - 19	8.35	1.82	0.53	1.14
4 – 3/8"	4.76 - 9.51	8.75	1.84	0.51	1.06
10 - 4	2 – 4.76	9.30	1.87	0.49	0.97
18 – 10	1 – 2.00	9.58	1.91	0.48	0.95
35 - 18	0.5 – 1.00	9.88	1.96	0.48	0.94

2.4 Determination of Water Absorption Ratio

The water absorption ratio of pumice was determined according the procedure in ASTM C 127-88. The experimental sample was placed into a container with 20°C water and after keeping it emerged in water for 24 hours, its water drained and dried until no water film was evident to bare eye on the granules. As soon as the dehydration process was finished, the sample was weighed and the saturated dry surface weight was determined. The sample in form of saturated dry surface was right after the weighing process placed into a trellis fence wire basket and dipped into a bucket filled with water at least 5 cm or even deeper. After the pumice sample was taken out of the bucket and made oven-dry, it was cooled until room temperature and its dry weight in air was recorded. The results of water absorption ratios for different pumice diameters are given in Table 3.

Table 3. The results of water absorption ratios for different pumice diameters

Sieve gap (No)	3/8" – 3/4"	4 – 3/8"	10 - 4	18 – 10	35 – 18
Sieve diameter (mm)	9.51 - 19	4.76 -9.51	2 – 4.76	1 – 2.00	0.5 – 1.00
Water absorption (%)	22.70	28.90	35.60	43.20	52.10

2.5 Sinking Test in Water

Due to their low density, the granular pumices may float on water. The sinking of pumice particles is due to the intrusion of water into the pores, and the sinking of pumice versus time for different grain size fractions was determined. Figure 6 shows the progressive variation in the dry unit weight of pumice particles of different diameters during the sinking test.

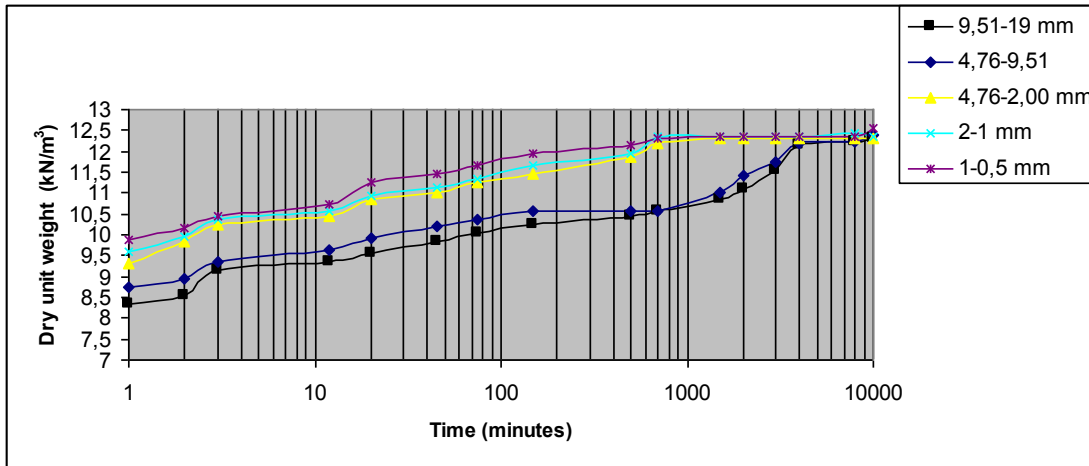


Figure 6. Sinking of pumice particles versus time for different grain size fractions

2.6 Mercury Porosimetry Experiments

In mercury porosimetry experiment, a particular pressure (P) of mercury entering the pores in the volume (V) is measured. In this experiment, the aim was to identify the size of the pores that a sample was completely purified from air, then coated with mercury with high pressure application steps. The results of this experiment, graphically volume (V) for graphic and a dimensionless pressure volume (V / Vtotal) corresponding to the pressure graph, can be shown in two ways. The mercury porosimetry experiments on pumice were performed in Ceramic Research Center of Anatolian University in Yunus Emre Campus. Three different diameters of pumice particles (8 mm, 4 mm and 2 mm) were tested, and the pore distribution curve is given in Figure 7.

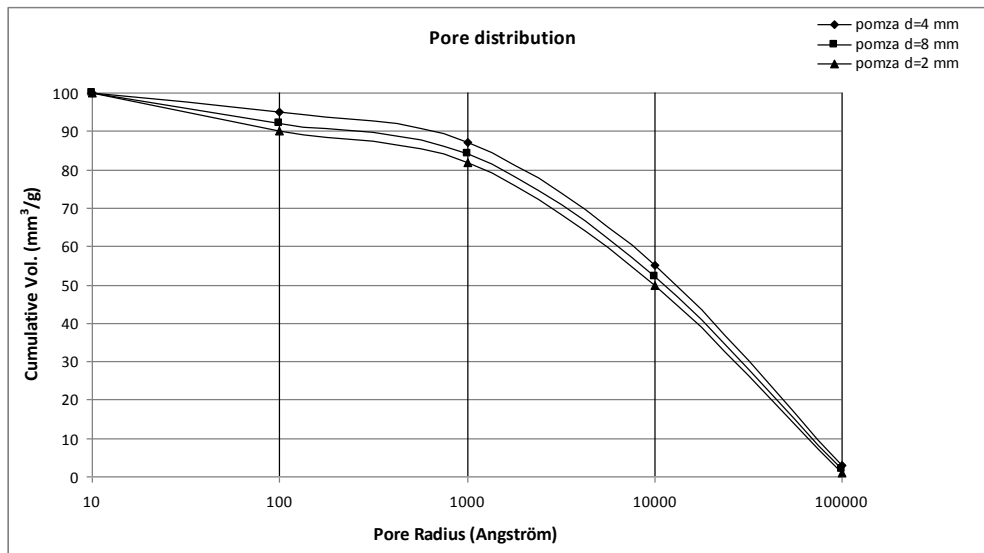


Figure 7. Pore distribution curve determined by mercury porosimetry experiments

2.7 SEM (Scanning Electron Microscopy) Analysis on Pumice

The pumice samples taken from the different working areas were analyzed with Scanning Electron Microscopy of Zeiss SUPRA 50 VP model in Anatolian University to observe the internal voids inside the samples. The SEM photograph of pumice can be seen in Figure 8.

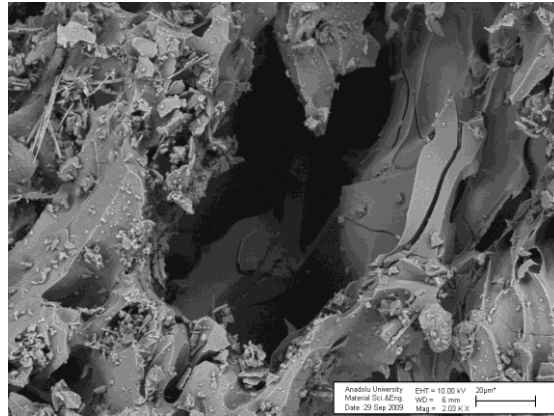


Figure 8. SEM photograph of pumice that has diameter of 6 mm taken from working area 2

2.8 Chemical Analysis on Pumice

The chemical analysis of pumice was executed in the chemistry laboratory of D.S.I. 4th Regional Directorate. In the chemical analysis, the rate of SiO₂ that erodes the rock in pumice was identified, and the chemical properties are given in Table 4.

Table 4. Chemical analysis of Nevşehir pumice

Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MgO	SiO ₂
3.10	14.90	2.90	0.08	4.10	2.75	0.08	68.5

2.9 Shear Box Test on Pumice

The shear box test of pumice was carried out according the procedure in ASTM D-3080. Due to the formation of different diameter pumices, the height of 2 cm and 100 cm² cross section ring were used for the shear box tests. The vertical stresses for each sample were respectively 32.6-65.2 and 130.5 kPa, and the samples were cut as 1mm/min. The shear box test results of different diameter pumices prepared as dry and 12% water content are given in Table 5.

Table 5. Shear box test results of different diameter pumices prepared as dry and 12% water content

Sieve gap (No)	Sieve diameter (mm)	Internal friction angle (φ) (dry)	Internal friction angle (φ) 12% water content
	Natural state of pumice	27.47	22.29
3/8" - 3/4"	9.51 - 19	29.43	24.56
4 - 3/8"	4.76 - 9.51	32.73	25.64
10 - 4	2 - 4.76	33.82	25.83
18 - 10	1 - 2.00	33.87	26.23
35 - 18	0.5 - 1.00	34.43	31.56

3 EVALUATION OF THE RESULTS

The specific gravity was determined with a calibrated pycnometer without any vacuum extraction (G_D = direct value) and with vacuum extraction (G_S =standart value). There is a substantial difference between these two values. In addition, as the particle size decreases, the specific gravity increases.

The results show similar characteristics with the study of Wesley's (2001) on New Zealand pumice that the specific gravity values increase with decreasing particle size (Figure 9).

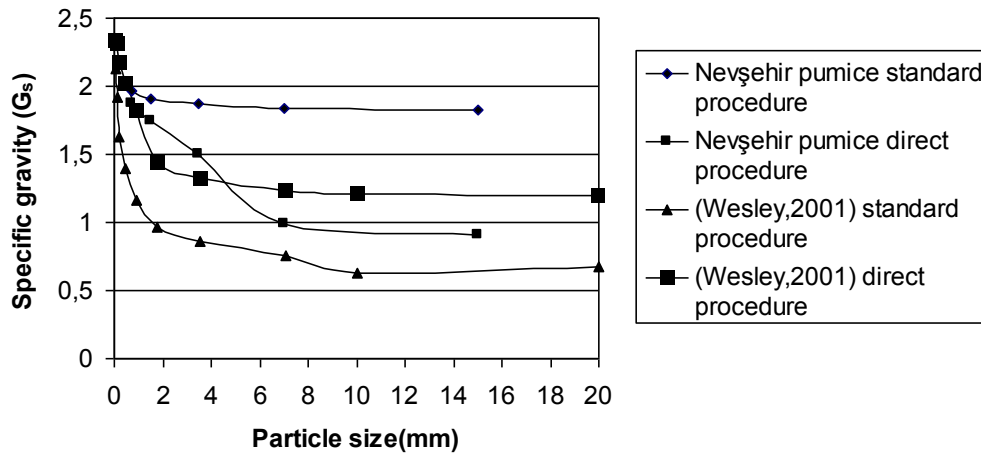


Figure 9. The comparison of specific gravity values with the literature (according to direct and standard procedure)

The results of dry unit weight are consistent with the literature. As the particle size decreased, the value of dry unit weight increased. Esposito & Guadagno (1998) calculated the dry unit weight of pumice samples of 16 mm, 8 mm, 4 mm, 2 mm and 0.85 mm diameters. While the dry unit weight of 16 mm pumice was obtained as 6.1 kN/m^3 , the dry unit weight of 0.85 mm pumice was determined as 7.5 kN/m^3 from the experiments. (Table 6).

Table 6. Dry unit weights of different diameter pumices (Esposito ve Guadagno, 1998)

Particle size (mm)	16 mm	8 mm	4 mm	2 mm	0.85 mm
Dry unit weight (kN/m^3)	6.1	6.3	6.6	7.1	7.5

For water absorption rates, as the particle size decreased, the value of water absorption increased. Esposito & Guadagno (1998) found that value as 67% for 16 mm diameter pumice and 70% for 0.85 mm diameter pumice. This difference is related with the structure of pumice.

The change in the dry unit weight of pumice for different diameters in sinking test is given in Figure 6. As can be seen from Figure 6, the voids of different size pumices were filled with water at the end of 10000 minutes (a period of approximately 1 week), and the dry unit weight increased 1.2-1.4 times. The average values were 10.000 angstrom were obtained as a result of the mercury porosimetric measurement as shown in Figure 6, 80% of the pores had a radius of larger than 2000 angstrom. The results were consistent with the literature; Esposito & Guadagno (1998) made the porosimetric measurements on 9.5-4.3 mm diameter Vesuvius pumice and obtained the pore distribution curve where the average radius values were identified as 11.000 angstroms and 80% of the pores had a radius >2000 angstrom.

The SEM analysis was carried out on the size of $d = 6 \text{ mm}$ pumice. As can be seen from Figure 8, the pores can be seen from the surface of pumice. This structure is similar with the internal structure of pumice that Esposito & Guadagno (1998) and Sparks (1978) also investigated.

The results of the chemical analysis are consistent with the literature that Başpınar & Gündüz (2006) investigated the geochemical analyses of Nevşehir pumice (Table 7).

Table 7. The results of chemical analysis of Nevşehir pumice Başpınar ve Gündüz (2006)

Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	MgO	SiO_2
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3.05	14.01	1.50	1.41	3.29	3.49	0.34	70.06
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As can be seen from Table 5, while the diameter of pumice decreases, the internal friction value of pumice increases for dry and 12% water content.

The reason for obtaining 12% water content in shear box tests is due to the winter conditions that the water was measured in winter and obtained %12.

4. RESULTS

Pumice soils can be considered to be unique in the panorama of geotechnical materials that their behavior is influenced by the presence of both particle pores and interstices between pumice particles. It has been shown that this can cause differences in the physical and volumetric parameters as well as in the behavior of the pumice soils.

The results showed that as the diameter of pumice decreases the specific gravity, dry unit weight, water absorption value and internal friction angle increase. Here, it can be seen that the bearing capacity of pumice varies depending on the particle diameter.

With penetration of water into the pores, the weight of pumice particles increases. Thus the slope stability is an important problem in this way.

ACKNOWLEDGEMENTS

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REFERENCES

- ASTM C136 - 06 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.
- ASTM C29 / C29M - 09 Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate.
- ASTM D854 - 10 Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer.
- ASTM C127 - 88 Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate.
- ASTM D3080 / D3080M - 11 Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions.
- Başpınar, E., L. Gündüz (2006) İnşaat Endüstrisinde Kullanılan Pomza Agregalarının Mineralojik ve Petrografik Özellikleri (Mineralogical and Petrographical Properties of Pumice Aggregates for Use in Civil Industry), 4. Ulusal Kırmataş Sempozyumu, İstanbul.
- Esposito, L., F. M. Guadagno (1998) Bulletin of Engineering Geology and the Environment, 57: 41-50.
- Pellegrino, A. (1966) Propetà fisico-meccaniche dei terreni vulcanici del Napoletano. AGI 7th Convention for Geotechnics, Cagliari, Italy 3 : 113-145.
- Pender, M.J., L.D. Wesley, T.J. Larkin, S. Pranjoto (2006) Geotechnical properties of a pumice sand. Soils And Foundations, Volume:46, Issue:1, Pages: 69-81.
- Soğancı, A.S. (2011) Nevşehir bölgesinde bulunan pomzaların taşıma gücü ve oturma yönünden geoteknik özelliklerinin belirlenmesi ve iyileştirilmesi, (Determination of the geotechnical properties of the pumice type soils in Nevşehir region in terms of load-bearing capacity and settlement and their stabilization) Ph.D. Thesis, Selcuk University, ix+219p., Konya.
- Sparks, RSJ (1978) Gas release rates from pyroclastic flows: an assessment of the role of fluidisation in their emplacement. Bull Volcan 41 :1-9.
- Wesley, L. (2001) Determination of Specific Gravity and Void Ratio of Pumice Materials. Geotechnical Testing Journal, Vol. 24, No. 4, pp. 418-422.