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Influence of freeze-thaw on strength of clayey soil stabilized with lime and perlite

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Abstract. Stabilization of clayey soil has been studied from past to present by mixing different additives to the soil to increase its strength and durability. In recent years, there has been an increasing interest in stabilization of soils with natural pozzolans. Despite this, very few studies have investigated the impact of pozzolanic additives under freeze-thaw cycling. This paper presents the results of an experimental research study on the durability behavior of clayey soils treated with lime and perlite. For this purpose, soil was stabilized with 6% lime content by weight of dry soil (optimum lime ratio of the the soil), perlite was mixed with it in 0%, 5%, 10%, 20%, 25% and 30% proportions. Test specimens were compacted in the laboratory and cured for 7, 28 and 84 days, after which they were tested for unconfined compression tests. In addition to this, they were subjected to 12 closed system freeze-thaw cycles after curing for 28 days. The results show that the addition of perlite as a pozzolanic additive to lime stabilized soil improves the strength and durability. Unconfined compressive strength increases with increased perlite content. The findings indicate that using natural pozzolan which is cheaper than lime, has positive effect in strength and durability of soils and can result cost reduction of stabilization.

Keywords: soil improvement; lime; perlite; freeze-thaw cycling; natural pozzolan

1. Introduction

Freezing-thawing process happening in seasonal freezing area cause strength and durability loss of soil. Soil structures weaken physically under the effect of freeze-thaw cycles (Konrad 1989, Ghazavi and Roustaie 2010). Durability of the soil is the ability to prevent the effects of freezing-thawing. Therefore, durability of stabilized soil with different additives in cold regions is crucial to ease their use in earthwork structures.

A considerable amount of literature has been published on lime stabilization of clayey soils (Clare and Crunchley 1957, Bell 1996, Akawwi and Al-Kharabsheh 2000, Rajasekaran and Rao 2002, Tonoz *et al.* 2004, Sivapullaiah and Lakshmikantha 2005, Arabani and Karami 2007, Manasseh and Olufemi 2008, Sakr and Shahin 2009, Al-Mukhtar *et al*. 2010, 2012, Bozbey and Garaisayev 2010, Cuisinier *et al*. 2011, Miqueleiz *et al*. 2012, Zukri 2013, Ciancio *et al*. 2014, Sante *et al*. 2014, Akcanca and Aytekin 2014, Onal 2015). During stabilization of clayey soils four types of reactions can take place between lime, silica and alumina. These reactions are cation exchange, particles aggregations and flocculation, carbonization and pozzolanic reaction (Jacques *et al*. 1990). In recent years, there have been an increasing concern of using pozzolanic materials (rice husk ash, silica fume, fly ash, slug etc.) in soil stabilization (Ahmed and Ugai 2011, Kamei *et al*. 2012, Canakci *et al*. 2015, Kaya 2016, Gupta and Kumar 2017, Mohanty *et al*. 2017). Some of these studies, different combinations were utilized with varied proportions in addition to lime to find out economical combination of lime and admixtures (Jha and Gill 2006, Olgun 2013, Calik and Sadoglu 2014, Yilmaz *et al.* 2015).

Perlite reserves of the world is around 6700 millions tons and studies have reported that it possesses pozzolanic characteristics (Erdem *et al*. 2007). The freeze-thaw durability of clayey soil stabilized lime and perlite has not been widely studied, while some research has been carried out on the freeze-thaw durability of soil stabilized with alternative materials (Wang *et al*. 2007, Qi *et al.* 2008, Zaimoglu 2010, Hazirbaba and Gullu 2010, Zorluer and Demirbas 2013, Zorluer and Gucek 2014). The major objective of this study was to investigate freezing-thawing effect on unconfined compressive strength of clayey soil stabilized with lime and perlite.

2. Experimental study

2.1 Materials

Soil used in this study was taken from a fine-grained soil deposit of Demirözü-Bayburt in the north east of Turkey. The classification of the soil is ‘low plasticity clay (CL)’ according to the Unified Soil Classification System. The grain size distribution curve of the soil used in this experimental study is shown in Fig. 1.

Index properties of soil, such as liquid limit, plastic limit, optimum water content, and maximum dry density, are summarized in Table 1. Atterberg limits, compaction

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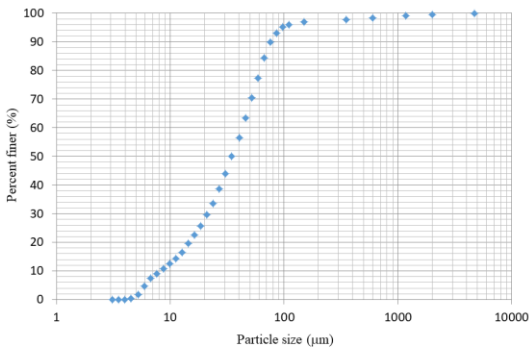

Fig. 1 Grain size distribution curve of clay soil

Table 1 Index properties of the expansive soil

Property	Value
USCS classification	CL
Liquid limit, LL (%)	48,8
Plastic limit, PL (%)	26,5
Plasticity index, PI (%)	22,3
Specific gravity	2,60
Optimum water content, w_{opt} (%)	23,0
Maximum dry density, ρ_{kmax} (Mg/m^3)	1,63
Color	Flavescent

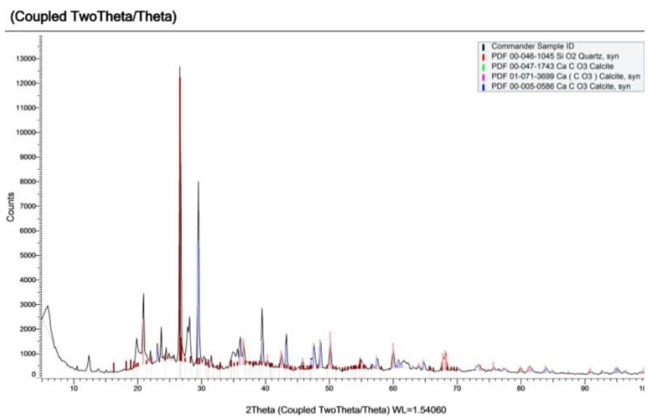

Fig. 2 X-ray diffraction of expansive soil

Table 2 Lime properties

Property	Value
$Ca(OH)_2$ (%)	85.80
Active CaO (%)	65.00
MgO (%)	1.40
SiO_2 (%)	0.23
Al_2O_3 (%)	0.11
Fe_2O_3 (%)	0.40
Density (Mg/m^3)	0.48
Grain specific gravity (Mg/m^3)	2.37
pH value	12.4

parameters and specific gravity were determined according to ASTM D4318 (2010), ASTM D698 (2012) and ASTM D854 (2014), respectively. Minerals of expansive clay soil is identified by X-ray diffraction, and the results are given in Fig. 2. X-ray diffraction analysis of the poor soil was accomplished using a Bruker D8 Discover X-ray diffractometer. As it can be seen from Fig. 2, the main mineralogical portion of the soil are quartz and calcite.

Active CaO ratio of the hydrated lime ($CaOH_2$) used in this study is 65% and physical and chemical properties of the lime are shown in Table 2. The grain size distribution curve of the hydrated lime used in this experimental study is shown in Fig. 3.

Perlite used in this study was taken from an institution located in Mollaköy-Erzincan, Turkey. Physical and chemical properties of the perlite are summarized in Table 3. From chemical composition results, it was seen that perlite shows siliceous nature. SiO_2, Fe_2O_3 and Al_2O_3 are the crucial ingredients for pozzolanic activity and the perlite consists 82.49% of these chemical compositions. X-ray diffraction test results of the perlite is illustrated in Fig. 4. The grain size distribution curve of the perlite used in this experimental study is shown in Fig. 5.

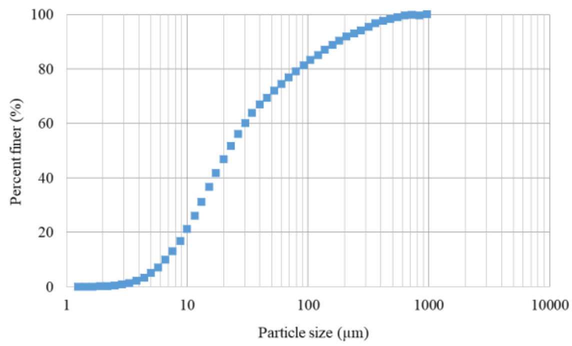

Fig. 3 Grain size distribution curve of hydrated lime

Table 3 Physical and chemical properties of the perlite

Property	Value
Specific gravity	2,24
Fineness (%) (passing 45 μm)	10.2
Ph	6.5
Specific surface area (cm^2/g)	3515
Atterberg limits	NP
Optimum water content, w_{opt} (%)	2.04
Maximum dry density, ρ_{kmax} (Mg/m^3)	1,56
Color	Gray
USCS classification	SW-SM
Chemical composition (%)	
Silica (SiO_2)	69.21
Alumina (Al_2O_3)	11.94
Iron oxide (Fe_2O_3)	1.34
Calcium oxide (CaO)	2.36
Potash (K_2O)	2.78
Magnesia (MgO)	0.94
Na_2O	5.42
SO_3	0.06
Loss of ignition	4.16

Table 4 Notations of test specimens

Test specimens	Notations
Soil	S
Soil and lime	SL
Soil, lime and perlite	SLP
Soil, lime and 5% perlite	SLP/5
Soil, lime and 10% perlite	SLP/10
Soil, lime and 15% perlite	SLP/15
Soil, lime and 20% perlite	SLP/20
Soil, lime and 25% perlite	SLP/25
Soil, lime and 30% perlite	SLP/30

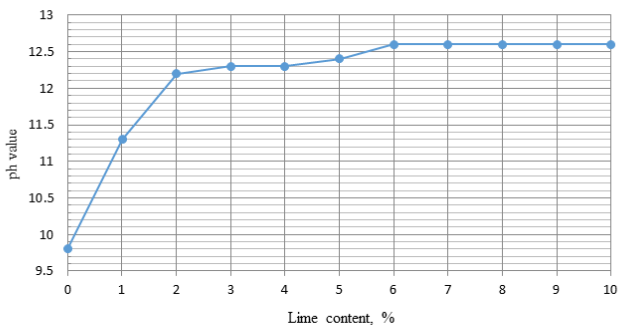

Fig. 6 Effect of various lime content on pH value

2.2 Sample preparation and testing procedure

In this experimental study, three types of test mixtures, namely soil (S), soil and lime (SL) and soil, lime and perlite (SLP) were compacted into Proctor compaction mold with standard Proctor energy at optimum water content. Compaction tests were carried out in compaction molds with a height 116.4 mm and a diameter of 101.6 mm. The samples laid into desiccators and the water content of the test specimens were kept constant until test time. Notations of test specimens are given in Table 4. The results of pH test and the variation of pH due to addition of lime is presented in Fig. 6.

As shown in Fig. 6, optimum lime ratio of the soil is found 5% that results in a soil-lime pH of 12.4 according to ASTM standards. However, studies (Mathew and Rao 1997, Al-Rawas *et al.* 2002) have consistently shown that, optimum amount of lime should exceed this value if an increase of strength is needed in soil stabilization. Because of this reason, optimum lime ratio of the soil came out as 6%.

Calik and Sadoglu (2014) point out that evaluating perlite in soil stabilization without lime is not effective and does not provide crucial improvement of the strength of poor soil. From this reason, all specimens of this study except natural soil were prepared with optimum lime ratio (6%).

3. Results and discussions

3.1 Atterberg limits and compaction parameters

The consistency limits were performed immediately after the specimens were prepared. It was seen that the liquid limit and plasticity index values of the natural soil sample are higher than all the additive mixtures. It has been found that with the addition of lime, liquid limit values were decreased. For SLP mixtures, the liquid limit values of the mixtures decreased with the increase of perlite ratio. Generally, in the plastic limit value of SLP mixtures an increase was observed with respect to the SL mixture. The results obtained from the consistency limit tests are

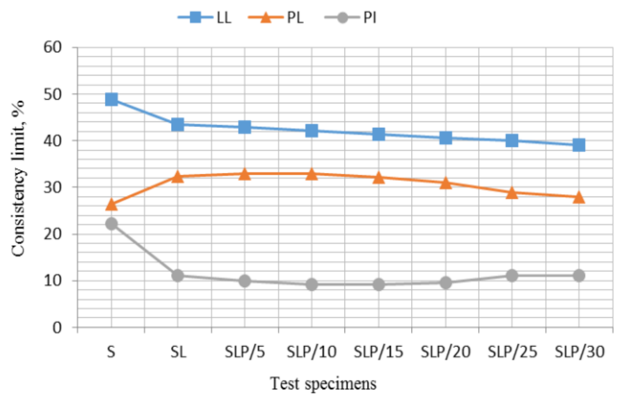

Fig. 7 Atterberg limits

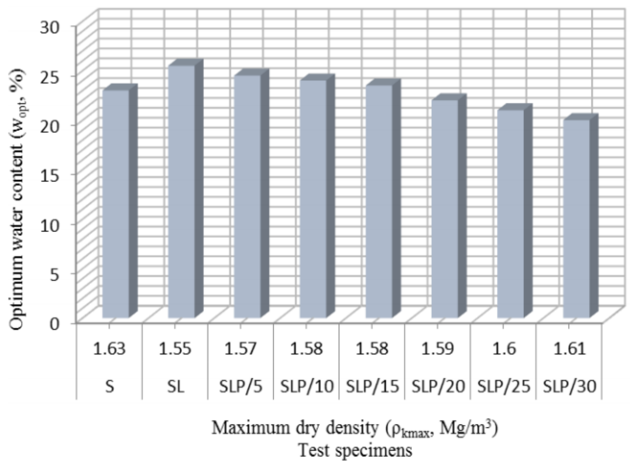

Fig. 8 Compaction parameters

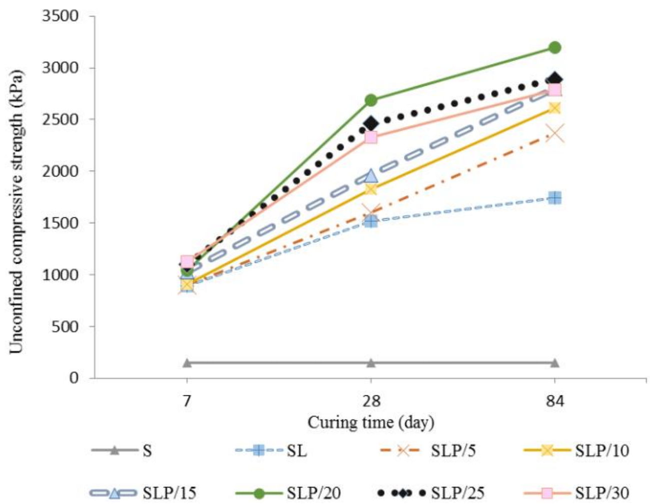

Fig. 9 Unconfined compressive strength of specimens

presented in Fig. 7.

Fig. 8 shows the experimental data on compaction parameters. From the data in Fig. 8, it is apparent that maximum dry density decreased and optimum water content increased with the addition of lime to the expansive soil. While the maximum dry density values of the SLP mixtures increase with respect to the SL mixture, the optimum water content values decrease. In general, the maximum dry density values of the treated samples vary between 1.55-1.61 Mg /m^3. It is observed that the maximum dry density values tend to increase with the increase of perlite in SLP mixtures.

When the optimum water content values are examined in treated mixtures, it has been found that optimum water content of SLP mixtures decreased with the increase of perlite ratio and SLP/30 has the lowest optimum water content. In general, the optimum water content values of the samples vary between 20% and 25.5%.

3.2 Unconfined compressive strength

Unconfined compressive strength test of specimens were performed after 7, 28 and 84 days of curing period and the differences of strength values are highlighted in Fig. 9. It is apparent from this figure that there was no increase of strength in poor soil samples after curing periods. The strength increased with the addition of lime. Until the optimum condition of lime and perlite (SLP/20) is reached, the strength increased with the increase of perlite in SLP specimens. In all curing periods, optimum content of perlite was found 20% in SLP specimens. After 84 days of curing period, it was seen that the highest strength result is obtained from SLP/20 mixtures with 3196.0 kPa.

3.3 Effect of the freeze-thaw cycles on unconfined compressive strength

The main target of this study was to investigate freezing-thawing behavior of fine-grained soil treated with lime and perlite. Therefore, special importance was given to this parameter to see the variation of strength with freeze-thaw phases. For freezing-thawing cycles, specimens were placed in a closed system freezing-thawing cabin at -20℃ for 24 hours and then +24℃ for thawing phase for 24 hours. Fig. 10 presents the freeze-thaw cabin system, specimens and experimental setup of uniaxial compression test. After 12 freeze-thaw cycles, unconfined compressive strength test was carried out to determine the strengths of S, SL and SLP specimens.

The strength results of specimens obtained from unconfined compressive test after 12 times freezing-thawing cycles are given in Fig. 11.

According to Fig. 11, it can be seen that the strength was generally increased with the increase of perlite ratio. As compared to SL specimen, unconfined compressive strength of SLP/20 specimen increased from 1230.3 to 2617.3 kPa. It can also be seen that, with the addition of perlite to the lime treated soil, the strength values increased. Similar results were obtained for fine-grained soils modified with lime and waste additives (Yilmaz *et al*. 2015).

To illustrate the effect of perlite on the durability values, the variation of strength loss was given in Fig. 12. The

Fig. 10 Close system freezing-thawing cabin and test specimens

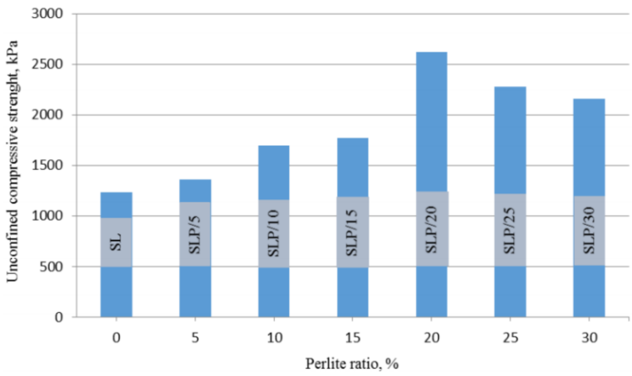

Fig. 11 Unconfined compressive strength after freeze-thaw cycles

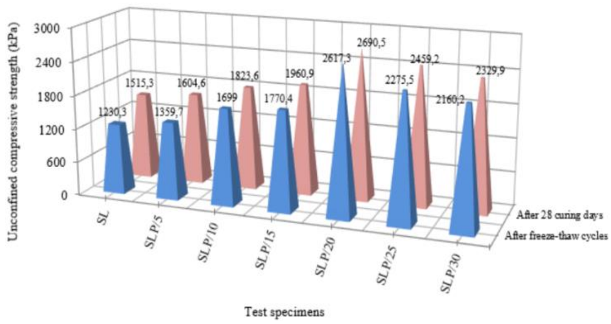

Fig. 12 Comparison of strength before and after freeze-thaw cycles

strength results of the specimens before and after freeze-thaw cycles can be compared in this figure. After 28 curing days the strength of soil was 148.3 kPa and after freezing-thawing effect it decreased 124.7 kPa. None of these values were statistically significant in comparison to SL and SLP specimens. Therefore, SL and SLP specimens were taken into account in Fig. 12. As it can be seen from the figure, strength loss of SL is around 19% after freeze-thaw cycles. While the strength loss of SL specimen was around 19%, it decreased up to 3% with SLP/20 specimens.

Generally, durability behavior of test specimens increased with the increase of perlite in SLP specimens. After 12 freezing-thawing cycles, the most remarkable effect of perlite was obtained on SLP/20 specimen as compared with other test specimens.

In the literature it was mentioned that NaOH raises the pH value of the specimen/medium and increases the stability of the calcium silica hydrate product and these reactions prevent detrimental effect of environmental factors (Al-Amoudi 2002). Because of the reaction of Na_2O with water, NaOH is formed. Accordingly, the higher amount of Na_2O in the perlite brings positive effect on the values of the strength and durability under freeze-thaw effects. The chemical bonds between Na_2O and SiO_2 improve the post-durability properties of SLP specimens. Hence it could be summarized that addition of perlite to the lime treated soil brings out more strength and durability against the effect of freezing-thawing cycles.

4. Conclusions

The effect of perlite on the strength and freeze-thaw durability of lime-stabilized soil was investigated by experiment. Based on the analysis of results, the following conclusions can be drawn:

• From the data obtained from the experiments, it was determined that perlite, which is a pozzolanic additive, directly affects the durability of lime treated soil.

• The most remarkable effect of perlite was observed on SLP/20 specimens with 20% perlite and 6% lime.

• The unconfined compressive strength of the specimens generally increased with the increase of perlite in SLP specimens.

The result presented in this paper have settled that the addition of perlite to the lime treated soil effects consistency limits, compaction parameters and strength. In addition, the noteworthy effect of perlite was noticed on durability of expansive soil under destructive freezing-thawing effect. In future investigations, it might be possible to use different soil and treatment conditions to make a more feasible engineering judgment.

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References

Ahmed, A. and Ugai, K. (2011), "Environmental effects on durability of soil stabilized with recycled gypsum", *Cold Reg. Sci. Technol.*, **66**(2-3), 84-92.

Akawwi, E. and Al-Kharabsheh, A. (2000), "Lime stabilization effects on geotechnical properties of expansive soils in Amman-Jordan", *Elec. J. Geotech. Eng.*, **5**(1), 1-10.

Akcanca, F. and Aytekin, M. (2014), "Impact of wetting-drying cycles on the hydraulic conductivity of liners made of lime-stabilized sand-bentonite mixtures for sanitary landfills", *Environ. Earth Sci.*, **72**(1), 59-66.

Al-Amoudi, O.S.B. (2002), "Attack on plain and blended cement exposed to aggressive sulfate environments", *Cement Concrete Compos.*, **24**(3-4), 305-316.

Al-Mukhtar, M., Khattab, S. and Alcover, J.F. (2012), "Microstructure and geotechnical properties of lime-treated expansive clayey soil", *Eng. Geol.*, **139**, 17-27.

Al-Mukhtar, M., Lasledj, A. and Alcover, J.F. (2010), "Behaviour and mineralogy changes in lime-treated expansive soil at 50ºC", *Appl. Clay Sci.*, **50**(2), 199-203.

Al-Rawas, A.A., Taha, R., Nelson, J.D., Al-Shab, T.B. and Al-Siyabi, H. (2002), "A comparative evaluation of various additives used in the stabilization of expansive soils", *Geotech. Test. J.*, **25**(2), 199-209.

Arabani, M. and Karami, M.V. (2007), "Geotechnical properties of lime stabilized clayey sands", *Arab J. Sci. Eng.*, **32**(1B), 11-25.

ASTM (2004), *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, Pennsylvania, U.S.A.

ASTM D4318 (2010), *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils,* West Conshohocken, Pennsylvania, U.S.A.

ASTM D698 (2012), *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort*, West Conshohocken, Pennsylvania, U.S.A.

ASTM D854 (2014), *Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer*, West Conshohocken, Pennsylvania, U.S.A.

Bell, F.G. (1996), "Lime stabilization of clay minerals and soils", *Eng. Geol.*, **42**(4), 223-237.

Bozbey, I. and Garaisayev, S. (2010), "Effects of soil pulverization quality on lime stabilization of an expansive clay", *Environ. Earth Sci.*, **60**(6), 1137-1151.

Calik, U. and Sadoglu, E. (2014), "Engineering properties of expansive clayey soil stabilized with lime and perlite", *Geomech. Eng.*, **6**(4), 403-418.

Canakci, H., Aziz, A. and Celik, F. (2015), "Soil stabilization of clay with lignin, rice husk powder and ash", *Geomech. Eng.*, **8**(1), 67-79.

Ciancio, D., Beckett, C.T.S. and Carraro, J.A.H. (2014), "Optimum lime content identification for lime-stabilised rammed earth", *Construct. Build. Mater.*, **53**, 59-65.

Clare, K.E. and Crunchley, A.E. (1957), "Laboratory experiments in the stabilization of clays with hydrated lime", *Geotech.*, **7**(2), 97-111.

Cuisinier, O., Auriol, J.C., Borgne, T.L. and Deneele, D. (2011). "Microstructure and hydraulic conductivity of a compacted lime-treated soil", *Eng. Geol.*, **123**(3), 187-193.

Erdem, T.K., Meral, Ç., Tokyay, M. and Erdoğan, T.Y. (2007), "Use of perlite as a pozzolanic addition in producing blended cements", *Cement Concrete Compos.*, **29**(1), 13-21.

Ghazavi, M. and Roustaie, M. (2010), "The influence of freeze-thaw cycles on the unconfined compressive strength of fiber-reinforced clay", *Cold Reg. Sci. Technol.*, **61**(2-3), 125-131.

Gupta, D. and Kumar, A. (2017), "Stabilized soil incorporating combinations of rice husk ash, pond ash and cement", *Geomech. Eng.*, **12**(1), 85-109.

Hazirbaba, K. and Gullu, H. (2010), "California bearing ratio improvement and freeze-thaw performance of fine-grained soils treated with geofiber and synthetic fluid", *Cold Reg. Sci. Technol.*, **63**(1-2), 50-60.

Jacques, L., Marc-Andre, B. and Marc, C. (1990), "Laboratory investigation on lime stabilization of sensitive clays: Shear strength development", *Can. Geotech. J.*, **27**(3), 294-304.

Jha, J.N. and Gill, K.S. (2006), "Effect of rice hush ash on lime stabilization", *J. Inst. Eng.*, **87**, 33-39.

Kamei, T., Aly, A. and Toshihide, S. (2012), "Effect of freeze-thaw cycles on durability and strength of very soft clay soil stabilised with recycled bassanite", *Cold Reg. Sci. Technol.*, **82**, 124-129.

Kaya, Z. (2016), "Effect of slag on stabilization of sewage sludge and organic soil", *Geomech. Eng.*, **10**(5), 689-707.

Konrad, J.M. (1989), "Physical processes during freeze-thaw cycles in clayey silts", *Cold Reg. Sci. Technol.*, **16**(3), 291-303.

Manasseh, J. and Olufemi, A.I. (2008), "Effect of lime on some geotechnical properties of Igumale shale", *Elec. J. Geotech. Eng.*, **13**(6), 1-12.

Mathew P.K. and Rao, S.N. (1997), "Effect of lime on cation exchange capacity of marine clay", *J. Geotech. Geoenviron. Eng.*, **123**(2), 183-185.

Miqueleiz, L., Ramírez, F., Seco, A., Nidzam, R.M., Kinuthia, J.M., AbuTair, A. and Garcia, R. (2012), "The use of stabilised Spanish clay soil for sustainable construction materials", *Eng. Geol.*, **133**, 9-15.

Mohanty, S.K., Pradhan, P.K. and Mohanty, C.R. (2017), "Stabilization of expansive soil using industrial wastes", *Geomech. Eng.*, **12**(1), 111-125.

Olgun, M. (2013), "The effects and optimization of additives for expansive clays under freeze-thaw conditions", *Cold Reg. Sci. Technol.*, **93**, 36-46.

Onal, O. (2015), "Lime stabilization of soils underlying a salt evaporation pond: A laboratory study", *Mar. Georesour. Geotechnol.*, **33**(5), 391-402.

Qi, J., Wei, M. and Song, C. (2008), "Influence of freeze-thaw on engineering properties of a silty soil", *Cold Reg. Sci. Technol.*, **53**(3), 397-404.

Rajasekaran, G. and Rao, S.N. (2002), "Permeability characteristics of lime treated marine clay", *Ocean Eng.*, **29**(2), 113-127.

Sakr, M.A. and Shahin, M.A. (2009), "Utilization of lime for stabilizing soft clay soil of high organic content", *Geotech. Geol. Eng.*, **27**(1), 105-113.

Sante, M.D., Fratalocchi, E., Mazzieri, F. and Pasqualini, E. (2014), "Time of reactions in a lime treated clayey soil and influence of curing conditions on its microstructure and behaviour", *Appl. Clay Sci.*, **99**, 100-109.

Sivapullaiah, P.V. and Lakshmikantha, H. (2005), "Lime stabilized illite as a liner", *Ground Improv.*, **9**(1), 39-45.

Tonoz, M.C., Ulusay, R. and Gokceoglu, C. (2004), *Effect of Lime Stabilization on Engineering Properties of Expansive Ankara Clay*, in *Engineering Geology for Infrastructure Planning in Europe*, Springer, Berlin, Heidelberg, Germany.

Wang, D., Ma, W., Niu, Y., Chang, X. and Wen, Z. (2007), "Effects of cycling freezing and thawing on mechanical properties of Qinghai-Tibet clay", *Cold Reg. Sci. Technol.*, **48**, 34-43.

Yilmaz, F., Kamiloglu, H.A. and Sadoglu, E. (2015), "Soil stabilization with using waste materials against freezing thawing effect", *Acta Physica Polonica A*, **128**(2B), 392-394.

Zaimoglu, A.S. (2010), "Freezing-thawing behavior of fine-grained soils reinforced with polypropylene fibers", *Cold Reg. Sci. Technol.*, **60**(1), 63-65.

Zorluer, I. and Demirbas, A. (2013), "Use of marble dust and fly ash in stabilization of base material", *Sci. Eng. Compos. Mater.*, **20**(1), 47-55.

Zorluer, I. and Gucek, S. (2014), "The effects of marble dust and fly ash on clay soil", *Sci. Eng. Compos. Mater.*, **21**(1), 59-67.

Zukri, A. (2013), "Pekan soft clay treated with hydrated lime as a method of soil stabilizer", *Proc. Eng.*, **53**, 37-41.