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The effects of additives and curing conditions on the mechanical behavior of a silty soil

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ABSTRACT

The effects of freeze–thaw processes on a natural silt soil stabilized with Class C fly ash and cement are investigated in this study. The silt was obtained from Soma near the city of Izmir, Turkey. The experimental study consisted of stabilizing the cylindrical soil specimens with fly ash and cement at various rates by compacting and then curing these specimens up to 28 days in a moist room at a constant temperature and controlled humidity. Specimens were separated into two groups: half of them were protected by a stretch film to prevent desiccation; the remaining were unprotected. After curing, specimens were subjected to a maximum of seven cycles of closed-system freezing and thawing. Then, unconfined compressive strength (UCS) tests were conducted on all specimens and the results were evaluated in terms of the amount of cementitious material included, curing conditions and the number of cycles. As a consequence, it was noted that specimens of high fly ash and cement content had greater strength values.

1. Introduction

Fly ash from coal-burning facilities, with its self-cementing property, can be used to improve cement and foundation soils. Over the last decades, the addition of fly ash and/or cement to fine soils has been widely used for developing desirable engineering properties, especially the construction of highways and airports.

Many studies in the literature are related to the use of fly ash in the improvement of engineering properties of soils. Turner (1997) looked at the performance of a foundation on a sandy soil stabilized with fly ash and compared it with the same soil reinforced with geosynthetics. He found that fly ash added soils had at least the same bearing capacity as those with geosynthetics. Çokça (2001) conducted compaction tests on cement stabilized Soma fly ashes, and indicated that increasing cement content decreases optimum water content as well as maximum dry density, while increasing specific gravity. Yıldız et al. (2004) determined that the unconfined compressive strength (UCS) of highly plastic Aksaray clay is fifteen times greater after a 28-day curing period. Likewise, the strength of low plastic Doganhisar clay is approximately two times higher after being stabilized. On the other hand, the strength values decrease 10–15% after freezing and thawing operations. Öztaş and Fayetorbay (2003) have observed the negative effect of freeze and thaw on aggregate stability. Qi et al. (2008) have utilized a silty soil to study the effects of freeze–thaw cycles. They discovered a critical dry unit weight, above which some of the engineering properties of soils they have considered, such as preconsolidation pressure, cohesion, and density, are not affected by further freezing and thawing. Yarbaşı et al. (2007) made a comprehensive study regarding the stabilization of granular soil by various additives, including red mud, lime, silica fume and fly ash. They employed resonant frequency, ultrasonic wave, CBR and compressive strength tests on stabilized specimens which were subjected to freeze/thaw conditions. The authors concluded that a number of additive combinations, particularly the silica fume–lime mixture is the best stabilizer of granular soil against the effects of freezing and thawing. Wang et al. (2007) have found that for a compacted clay, the physical and mechanical properties drastically changed with increasing freezing–thawing cycles. The resilient modulus and the failure strength reached minimal values after three to seven cycles of freeze–thaw; therefore, they noted that the strength of soils in cold regions should be designed for soils exposed to seven freeze–thaw cycles.

Geotechnical properties of natural and stabilized soils are affected by freezing/thawing cycles. Strength parameters of saturated soils are especially much more sensitive to freezing/thawing than unsaturated soils. In this respect, freezing/thawing conditions are crucial considerations for transportation infrastructures as well as geotechnical applications in cold regions. As a result of seasonal changes that are the main reason for freezing and thawing, soil behavior is fundamentally changed: crack propagation and stability failures occur following cycles of freezing/thawing. Exposure of large voids within fine grained soils to low temperatures is the main reason that glaciers form. Subsequently, water within smaller voids also freezes. When frozen, the volume of water increases approximately 9%; therefore, unavoidable cracks occur in the soil (Yıldız et al., 2004). As a consequence of freezing/thawing cycles, existing cracks widen and crack formations

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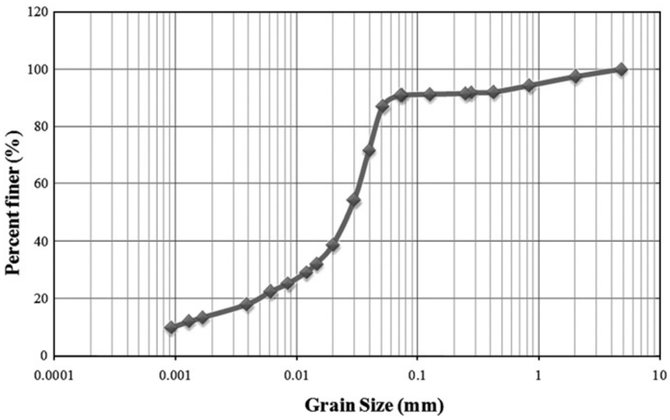

Fig. 1. Grain size distribution of the silt soil.

Table 2
Physical properties of the fly ash, cement and soil.

Physical property	Soil
Soil class according to USCS/ ASSHTO	ML/A-4
Specific gravity (G_s)	2.73
Liquid/plastic limit (%)	30 / 24
Physical property	Fly ash
Specific density (g/cm^3)	2.21
Specific area (cm^2/g)	1.47
Amount above the 0.045 mm. sieve size, by weight (%)	33
Amount above the 0.090 mm. sieve size, by weight (%)	14.3
Physical property	Cement
Type	CEM-I 42.5
Specific density (g/cm$^{3)}$	3.13
Specific area (cm^2/g)	3670
Amount above the 0.032 mm. sieve size, by weight (%)	18.20
Amount above the 0.090 mm. sieve size, by weight (%)	0.70

propagate. The strength of the soil decreases due to the increasing size and number of cracks. It should be noted that the thawing of a frozen layer commences simultaneously from all surfaces.

Several studies have demonstrated that freezing/thawing cycles decrease soil stability considerably (Lee et al., 1995; Konrad, 1989; Simonsen and Isacsson, 2001; Khoury and Zaman, 2002; Kværnǿ and Øygarden, 2006). However, Lehrsch (1998) advocated just the opposite: an increase in soil stability as a result of freezing. The cracking and failure stemming from freezing/thawing can be explained by a decrease in permeability of the soil (White, 2002). Shear strength and stability of soils usually exhibit the lowest values after winter seasons leading to failure.

In this investigation, laboratory Unconfined Compressive Strength (UCS) Tests were performed on silty soil specimens stabilized with fly ash (originated from Soma thermal plant) and Portland cement to observe strength gains with different mixing compositions. Moreover, the effect of fly ash and cement addition on freezing/thawing resistance of silty soils was also studied. Consequently, economical and performance based evaluations were made for determining optimum contents. The silt was stabilized by 10% and 30% addition of fly ash, and 2% and 8% of cement, by weight. After the compaction process, uniaxial tests were performed on silty specimens subjected to various freezing and thawing cycles (one, three and seven) under different curing conditions.

2. Materials and test procedure

2.1. Properties of tested materials

Silt specimens were collected from Turgutlu, in the Izmir region. The soil was classified following a wet sieve analysis and the determination of Atterberg limits. Soil was classified as A-4 silty soil and as low plasticity sandy and clayey silt (ML), based on AASHTO and Unified Soil Classification System (USCS), respectively.

Grain size distribution curve of the silt combines the data obtained from dry/wet sieve analyses and hydrometer tests (Fig. 1). The specific gravity (G_s) was found as 2.73. The liquid and plastic limits as well as plasticity index were 30, 24, and 6%; respectively.

The stabilizer, a fly ash originating from lignite obtained from the Soma thermal power plant, had a specific density of 2.21 g/cm^3 and a specific area of 2351 cm^2/g. The material larger than a diameter of 0.045 mm and 0.090 mm were 33% and 14.3%, respectively. Chemical properties of the fly ash are given in Table 1.

The Portland cement used in this study (CEM-I 42.5) had a specific density of 3.13 g/cm^3 and a specific area of 3670 cm^2/g. Particle diameter of the cement larger than 0.09 mm and 0.032 mm were 0.70% and 18.20%, respectively. Physical properties of fly ash, cement and soil are tabulated in Table 2.

2.2. Specimen preparation and testing methodologies

Sixteen different silt specimens were prepared by adding 10, 20, and 30% of fly ash as well as 2, 5 and 8% of cement in various combinations. Properties of the specimens are listed in Table 3, where FA stands for fly ash, and C for cement.

In addition to the determination of particle size distribution and values of Atterberg limits, standard Proctor tests were conducted to find out the optimum moisture content and maximum dry unit weight of the mixtures under consideration. Finally, unconfined compression tests were carried out on specimens subjected to freezing/thawing to investigate the loss of strength under cold weather conditions. The procedure consisted of freezing the cured specimens at −25 °C in a freezer for 24 h, and then thawing for another 24 h at a temperature of +22 °C and a relative humidity of approximately 98%. In the first testing group, the

Table 1
Chemical properties of the fly ash.

Chemical composition	Fly ash (%)
Alumina (Al_2O_3)	23.55
Ferric oxide (Fe_2O_3)	4.91
Calcium oxide (CaO)	18.67
Magnesium oxide (MgO)	1.54
Silica (SiO_2)	45.98
Sulphur oxide (SO_3)	1.47
Na_2O	0.24
Free CaO	0.64

Table 3
Abbreviations and the properties of the test samples.

Sample	Fly ash (%)	Cement (%)	LL	PL	PI
Natural soil	–	–	30.20	24.28	5.92
2C	–	2	37.82	26.98	10.84
5C	–	5	42.03	30.51	11.52
8C	–	8	42.50	33.12	9.38
10FA	10	–	36.90	26.66	10.24
20FA	20	–	36.51	29.78	6.73
30FA	30	–	37.17	30.59	6.58
10FA2C	10	2	38.87	29.47	9.40
20FA2C	20	2	35.42	29.31	6.13
30FA2C	30	2	35.10	29.79	4.63
10FA5C	10	5	44.29	32.84	11.45
20FA5C	20	5	38.80	30.08	8.72
30FA5C	30	5	36.81	31.13	5.68
10FA8C	10	8	41.56	33.81	7.75
20FA8C	20	8	38.52	30.59	7.93
30FA8C	30	8	39.85	32.60	7.25