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Liquid and plastic limits of fine-grained soils treated with ice, snow, and vapor

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Abstract

It is a well-known fact that water content has a significant effect on the engineering properties of fine-grained soils. There is a close relationship between consistency limits and geotechnical parameters of fine-grained soils. A study was conducted to investigate the effect of water phase on the consistency limits of 3 silt samples with a plasticity that varied between low and high. In the tests, distilled water, natural snow, natural ice pieces, and subboiled vapor were used as mixture liquids. The tests indicated that liquid limit values obtained at all of the water phases were comparable for low-plasticity silt samples. However, liquid limit values obtained at the snow, ice, and vapor phases were somewhat greater than that at distilled water. On the other hand, the plastic limit value had a tendency to decrease at the snow, ice, and vapor phases in comparison with that at distilled water for all of the soil samples.

Key Words: Plastic limit, liquid limit, silt, ice, snow, vapor

1. Introduction

The consistency limits (i.e. the liquid, plastic, and shrinkage limits) are water contents at certain limiting or critical stages in soil behavior. They define the transitions between the liquid, plastic, and brittle solid stages of a fine-grained soil. In about 1911, Swedish scientist Albert Atterberg was the first to develop a method for describing the limit consistency of fine-grained soils on the basis of water content (Das, 1983). Since then, these limits have been called Atterberg limits. The liquid and plastic limits (w_L and w_P, respectively) are especially extensively used for the identification, description, and classification of fine-grained soils and as a basis for the preliminary assessment of their mechanical properties where data on in situ parameters can be difficult to obtain.

Temperature changes induced in foundation soils and ground water arise from many different sources. In seasonally frozen areas, solid soil particles and pore water can be exposed to serious temperature differences, particularly during freeze-thawing cycles (Konrad, 1989; Qi et al., 2008). On the other hand, hot buried pipes,

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thermal spring areas, radioactive waste depositories, buried electricity cables, and contaminated landfill sites also cause temperature changes in the soil components (Jefferson and Rogers, 1998; Mitchell and Soga, 2005). Moreover, several researchers noted that changes in temperature can and will occur during sampling (Youssef et al., 1961; Mitchell and Soga, 2005). Consequently, the parameters measured in the laboratory may be unrepresentative of the true behavior of a soil in the field. The question then arises as to how these changes will affect the properties of a soil.

It should also be pointed out that many earth structures, such as impermeable liners of waste landfills, levees, and dams, are constructed of fine-grained soils. In these geotechnical engineering applications in which soils are used as an engineering material, undesirable volume changes, such as those caused by frost action, swelling, and shrinkage, may be controlled by using different phases of water (i.e. ice, snow, and vapor) as mixing liquids. Similarly, it was reported that ice pieces used as a mixing liquid instead of water could be preferred in casting bulk concrete for a dam to prevent the shrinkage cracks caused by temperature changes (Maraş et al., 1998).

Therefore, it seems reasonable to suggest that the temperature susceptibility of a soil-water compound could be evaluated using the consistency limits. Evaluation of the liquid and plastic limits at different phases of water could indicate how temperature affects key design parameters, by utilization of the various correlations that exist. The consistency limits would thus provide a quick and simple means to indicate preliminary effects of temperature and help evaluate whether further complex and expensive testing would be required.

The majority of the currently published literature is about the influence of elevated temperature changes in solid soil particles on the engineering properties of clay soils (Youssef et al., 1961; Ctori, 1989; Jefferson and Rogers, 1998; Tan et al., 2004). A limited number of investigations on the effect of temperatures below 0 °C on soil behavior are also available in the literature (Konrad, 1989; Hohmann-Porebska, 2002). However, there are almost no previously published studies on the effect of temperature changes, including both elevated temperatures and those below 0 °C, in pore water components on soil behavior.

In this study, a series of liquid and plastic limit tests (w_L and w_P) were carried out by using different phases of water in order to indicate the likely effect of any changes in the temperature of water components on the consistency properties of soils. Distilled water, natural snow, natural ice pieces, and subboiled vapor were used as mixture liquids in the tests. The tests were repeated on 3 different fine-grained soil samples with plasticity varying between low and high. The results of the physical tests were compared and discussed.

2. Experimental study

Soils used in this study were obtained from fine-grained soil deposits in the city of Erzurum in the eastern Anatolian region of Turkey. In this region, there is a long winter, and snow remains on the ground from November until the end of April. From the data obtained at a station in Erzurum between 1988 and 2005, the long-term mean temperature was 5.1 °C, the daily temperature range was 15.0 °C, the highest temperature measured was 35.6 °C, and the lowest temperature was –37.2 °C (Toy et al., 2007). This region also has rich thermal water sources such as hot spring resorts. Hence, these soil deposits resemble soils exposed to serious temperature differences and are used in many engineering works in Erzurum.

Liquid and plastic limit tests were conducted on 3 different fine-grained soil samples with plasticity varying from low to high. For the tests, the soil samples were washed through a BS200 sieve (d = 0.076 mm) and dried in an oven at approximately 105 ± 5 °C for 24 h. One of the soil samples could be classified as high-plasticity silt (MH) and the others as low-plasticity silt (ML) according to the Unified Soil Classification System. Some index properties of the soils are given in Table 1.

Table 1. Some index properties of soils used in the study.

Soil Sample		ML-1	ML-2	MH
Clay Content	< 0.002 mm (%)	7	-	43
Fine Grain Content	< 0.076 mm (%)	62	92	99
Specific Gravity	G_S	2.76	2.69	2.79
Liquid Limit*	w_L (%)	31	49	60
Plastic Limit	w_P (%)	23	35	50
Plasticity Index	I_P (%)	8	14	10
Soil Class (USCS)		ML	ML	MH

*Obtained from fall cone test.

Distilled water, natural snow, crumbled natural ice pieces, and subboiled vapor were used as mixture liquids in the tests. Snow and crumbled natural ice pieces were mixed with the dried soil, similar to distilled water. Vapor produced by an electrical boiling machine was applied to the soil samples through a thin steel pipe under atmosphere pressure. Soil samples were mixed with water, snow, ice, and vapor until a thick homogeneous paste was formed. Once the mixture process was completed, the tests were carried out as quickly as possible to ensure that temperature losses were insignificant. All mixing and testing operations were conducted at room temperature.

Measurements of the liquid limit with a cone penetrometer (BSI, 1990) were preferred since the results have greater repeatability, are easier to determine, and are less subjective than those obtained with a Casagrande device (Wroth and Wood, 1978; Houlsby, 1982; Koumoto and Houlsby, 2001). The apparatus consists of a penetrometer fitted with a 30° cone and stainless steel 35 mm in length. Some of the soil paste was placed in a cylindrical metal cup, with an internal diameter of 55 mm and a depth of 40 mm, and leveled off at the rim of the cup to give a smooth surface. The cone was lowered so that it just touched the surface of the soil in the cap, the cone being locked in its support at this stage. The cone was then released for a period of 5 s and its depth of penetration into the soil was measured. A little more of the soil paste was added to the cup and the test was repeated until a consistent value of penetration was obtained. The entire test procedure was repeated at least 4 times, using the same soil sample but increasing the water content each time by adding the mixture liquid. The penetration values covered a range of approximately 15 to 25 mm. The tests were carried out from the drier to the wetter state of the soil. Cone penetration was plotted against water content and the best straight line fitting the plotted points was drawn. The liquid limit was defined as the percentage water content corresponding to a cone penetration of 20 mm.

The plastic limit tests were performed by following the conventional ASTM D4318 technique (American Society for Testing and Materials, 2005). For the determination of the plastic limit, the soil was mixed with the different phases of water until it became sufficiently plastic to be molded into a ball. Part of the soil sample (approximately 2.5 g) was formed into a thread. The thread was placed on a glass plate and rolled until the soil sheared both longitudinally and transversely, when the thread had been rolled to a diameter of about 3 mm and a length of about 3-9 mm. The procedure was repeated using 3 more parts of the sample and the percentage water content of all of the crumbled soil was determined as a whole. This water content was defined as the plastic limit of the soil.

3. Results and discussion

Liquid limit (w_L) values obtained from the fall cone tests are shown in Table 2 for each soil sample treated with a different phase of water. Figure 1 shows the variation of the liquid limit with the phase of water used as the mixture liquid. It could be seen that the liquid limit was found to be nearly the same (i.e. around 30%) at all of the water phases for the ML-1 soil sample. The liquid limit also remained almost constant (i.e. around 50%) with the changing of the phase of mixing water for the ML-2 soil sample. On the other hand, for the MH soil sample, somewhat greater liquid limit values were obtained when snow, ice, and vapor were used as the mixture liquid instead of distilled water. However, the increase in the liquid limit was more pronounced for the vapor phase, found to be around 35% (i.e. from 60% to 81%). This could be attributed to coagulation promoted by increased temperature, evidence for which was also presented elsewhere (Jefferson and Rogers, 1997).

Table 2. Liquid limit values (%).

	Soil Sample		
Mixture Liquid	ML-1	ML-2	MH
Water	31	49	60
Snow	30	53	63
Ice	29	51	66
Vapor	33	48	81

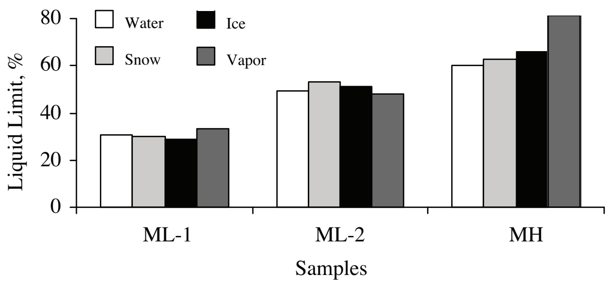

Figure 1. Variation of the liquid limit with the phase of mixture liquid.

The plastic limit values obtained by using different phases of water are given in Table 3 for all of the soil samples. Variation of the plastic limit with the water phase is shown in Figure 2. It could be said that the plastic limit had a tendency to decrease at the snow, ice, and vapor phases in comparison with that at distilled water for all of the soil samples. However, the rate of reduction in the plastic limit was more noticeable at the vapor phase. For ML-1, ML-2, and MH soil samples, the decrease in the plastic limit at the vapor phase was around 20% (i.e. from 23% to 18%), 60% (i.e. from 35% to 15%), and 35% (i.e. from 50% to 33%), respectively. This may be due to the fact that at the plastic limit, where water is mostly adsorbed (Seed et al., 1964), the soil particles impart an added lubrication, thus reducing the frictional resistance at the particle contacts. This, in effect, reduces the water content needed to achieve a certain strength and hence decreases the w_P value (Jefferson and Rogers, 1997). This is consistent with the effects of the structural status of the water and the nature of the interparticle forces (Mitchell and Soga, 2005).

It should be pointed out that there is no general consensus regarding the effect of temperature on the consistency limits of fine-grained soils. Most of the researchers observed a reduction in the w_L values of a variety of clay soils with elevated temperatures (Youssef et al., 1961; Ctori, 1989; Basma et al., 1994; Abu-Zreig et al., 2001). On the other hand, Jefferson and Rogers (1998) reported that the liquid limit increased with temperature for smectitic clay, whereas a very slight decrease occurred with kaolinite. Previous authors have suggested that these results could be explained in terms of changes to the double layer, the specific surface area, the viscosity of water, coagulation, and the geometrical rearrangement of the particles with temperature. Mineralogy and chemical compounds are also clearly significant factors in the engineering properties of fine-grained soils. Moreover, some researchers reported that the composition and chemistry of pore water had a very important effect on the consistency limits (Rao et al., 1993; Arasan and Yetimoğlu, 2008; Yukselen-Aksoy et al., 2008). It is most likely that the results are produced by a combination of effects.

Table 3. Plastic limit values (%).

	Soil Sample		
Mixture Liquid	ML-1	ML-2	MH
Water	23	35	50
Snow	16	30	50
Ice	17	31	42
Vapor	18	15	33

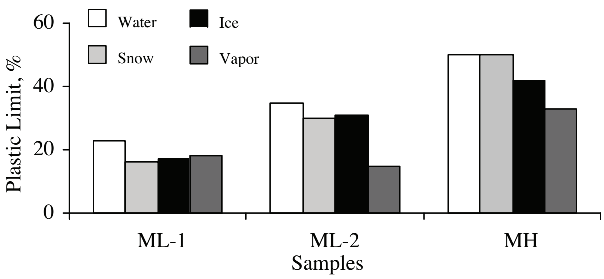

Figure 2. Variation of the plastic limit with the phase of mixture liquid.

It should also be added that differences in mixture liquid quality could be expected due to the possible melting of ice and snow, and vapor condensation at testing room temperature. It was reported that the differences in water quality could have a significant effect on the engineering properties of fine grained-soils, as well (Gleason et al., 1997; Sridharan and Nagaraj, 2005).

4. Conclusions

A series of liquid and plastic limit tests were conducted to investigate the effects of water phase on the consistency behavior of fine-grained soils. Tests were repeated on 3 different silt soil samples with a plasticity varying between low and high (i.e. ML-1, ML-2, and MH). Distilled water, natural snow, crumbled natural ice pieces, and subboiled vapor were used as mixture liquids in the tests. The study brought forth the following conclusions.

The liquid limit was not affected significantly by the phase of water for low-plasticity silt samples (i.e. ML-1 and ML-2). On the other hand, somewhat greater liquid limit values were obtained when snow, ice, and vapor were used as the mixture liquid than that of distilled water used for the high-plasticity silt sample (i.e. MH).

The plastic limit value had a tendency to decrease at the snow, ice, and vapor phases in comparison with that at distilled water for all of the soil samples. However, the rate of reduction in the plastic limit was more noticeable at the vapor phase.

Especially in cold regions, potential changes in the liquid and plastic limits of fine-grained soils may cause significant variations in their other geotechnical properties. Since the silt soils used in this study showed a nonactive character, the temperature of the pore water generally seemed to have a less significant effect on the consistency limits. On the other hand, one would expect that clays with a larger specific surface area, and hence interparticle contacts that are more dominated by adsorbed water, are much more sensitive to the temperature changes of the pore water. Therefore, to make more reasonable judgments and conclusions, further studies using identical clay minerals are needed to investigate the effect of the temperature of pore water on consistency limits.

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