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Effect of Method of Soil Drying On Atterberg Limits and Soil Classification

Ahmed Raad Al-Adhadh[1], Haider Kadhem Sakban[2], Zahraa Tawfiq Naeem[1]

[1]Department of Civil Engineering, Engineering College, Al-Muthanna University, Al-Muthanna, Iraq
[2]Department of Civil Engineering, Engineering College, University of Thi-Qar, Thi-Qar, Iraq

ahmad_al_iraqi2000@yahoo.com

Abstract. One of the most significant factors that effects the soil classification is Atterberg limits, liquid limit and plastic limit. Atterberg limits were developed by a Swedish scientist at the early 1900's called Atterberg. These limits could express the consistency of fine-grained soils due to variety of water content. These limits divide the soil into four major states, solid, semi-solid, plastic, and liquid state. According to American Standard for Testing and Materials (ASTM), to check liquid limit and plastic limit tests for a soil, the soil should be dried before the test for preparation purpose. ASTM specified two ways to dry the soil specimens, oven dry and air weather dry and both should give same results. Most of engineers will go with dry oven method to speed up the specimen preparation process assuming there is no any difference between these two methods of drying. In this research, the effect of the drying method has been studied. The results showed that the drying method has a significant effect on the liquid and plastic limits and then on the classification of soils. The soil specimens of this research were brought from all over Iraq cities to ensure studying different soils that could exhibits different behaviors.

1. Introduction

The classification of soil is considered major factor for designing geotechnical structures, no matter what the use of soil is, either supporting soil or as a constructional soil. Supporting soil could be existing under shallow foundations such as spread footings or mat foundations, around and below deep foundations such as piles and drill shafts, behind the retaining walls etc. on the other hand constructional soil could exist in all earth structures such as earth dams. All these geotechnical structures required deep study about the soil physical properties before getting started the structural design. The physical properties of soil and then the design of the geotechnical structure significantly depend on the plasticity of soil, which can be expressed by Atterberg limits [1]. Atterberg limits, liquid limit and plastic limit, were firstly developed by the Swedish scientist namely Atterberg at the early 1900's [2]. The consistency limits are greatly important to classify the soils, Serge Leroueil [3] has made a study on Illinois soil properties showed a relevant relationship between Atterberg limits and some engineering properties of soil. For example, there are more than a relation among the consistency limits and some physical and chemical properties such as the organic content matter, percentage of clay particles smaller than 0.002 mm, percent of Illite and Montmorillonite in the clay, percent of silt particle with size range between 0.05 and 0.002 mm. Haigh [4] has correlated the liquid limit with the clay strength and the plastic limit with the soil capillary suction. Therefore, the importance of Atterberg limits could be clearly visualized due to the previous studies. However, not many research studies are available to estimate the correlation between the effect of way of calculating consistency limits and soil classification. In this paper, a study has been made to show the effect of the drying method of soil on the values of liquid and plastic limits and then on the classification of soil.

1.1. Atterberg Limits

Fine-grained soils can be remolded in presence of water without crumble if clay minerals are existing. This phenomenon happened due to the cohesion exists between particles because of the water surrounding them [5]. There was a method to describe the consistency of fine-grained soil concerning the change of water contents. The Swedish scientist Atterberg developed this method. The consistency limits were proposed to distinguish among four states of soil. These four states of soil are solid, semi-solid, plastic, and liquid state, stated from low to high moisture content respectively [6]. The consistency limits among them are shrinkage limit to separate between solid and semi-solid state, plastic limit to separate between semi-solid and plastic state, liquid limit to separate between plastic and liquid state as shown in figure 1. In this study, it is focused on the effect of liquid and plastic limits due to their important on the classification of fine-grained soils.

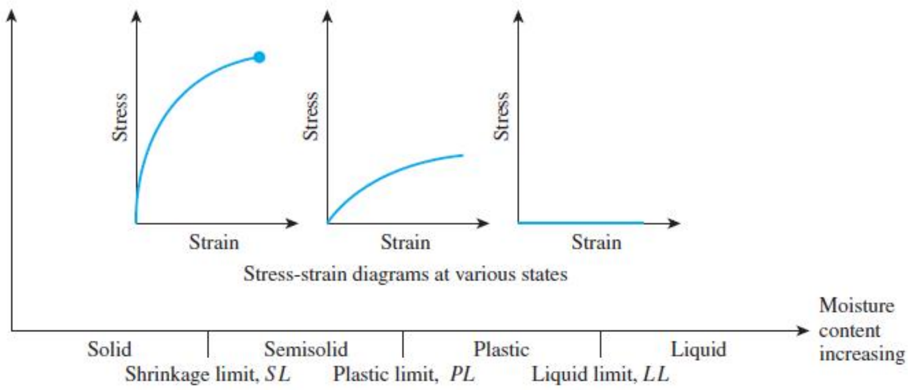

Figure 1. The consistency limits and soil states Das [5].

1.1.1. Liquid Limit. The liquid limit is can be described by the water content that transmits the soil from plastic to liquid state. In other words, the soil is transmitted to a state like a liquid if the water content increased passing the liquid limit, Sridharan [7]. Two methods are specified by ASTM D4318 [8] to make liquid limit test. These two methods are the one-point liquid limit and multipoint liquid limit. The first method is not quite precise as long it takes one test in consideration and the number of blows should be ranged between 20 and 30. Otherwise, a second method depends on setting up the moisture content to exhibit the required number of blows. Therefore, the second method is more precise than the one-point liquid as long as it depends more than one point for evaluating the liquid limit. Three liquid limit test must be made at least to ensure the required precise. The first test is made with a water content corresponding to a number of bows of 25 to 35 blows. The second test is made with a water content corresponding to a number of 20 to 30 blows and the last one with is done with a water content required to achieve 15 to 25 blows. Multipoint liquid limit method is the method that has been used in this study due to its accurate.

1.1.2. Plastic limit. The ASTM D4318 [8] procedure is strictly followed. Two method can be followed to calculate the plastic limit. First method is made by rolling the soil with hand at sufficient pressure by the palm of hand or the fingers, Haigh [2]. Second method is the rolling machine method. The first method, hand roll method, has been used in this study.

1.2. Soil preparation method

According to ASTM D4318 [8], there are two ways for preparing the specimens, dry preparation method and Wet preparation method. In this paper, dry preparation method will be dependent. Two different drying methods are mentioned in the ASTM D4318 [8], weather temperature drying method and oven drying method. The weather temperature drying method includes that the soil remains in the weather for days until its weight becomes constant with time. On the other hand, the oven drying method consists of placing the soil in the oven at temperature of about 60°C until the soil pulverized easily. After drying, the soil should be pulverized with a rubber hummer to avoid crushing the soil particles. After that, the soil is sieved on sieve No. 40 taking in considerations that pushing the soil particles to make them pass the sieve is forbidden. Two ways are allowed to remove the particle stuck in the sieve opening, brushing the sieve with a brush or washing the sieve, and the first one is dependent in this study. The sample could be divided into two parts, one of them dried in oven and the other exposure to the weather temperature to be dried naturally. The portion of the sample used for the liquid limit test is mixed with different amount of water to achieve the corresponding number of blows. After the liquid limit test is done, small amount of soil, about 20 g could be used for the plastic limit test [9]. The 20 g is used for the plastic limit test after reducing the amount of water in the soil to make it easy to be rolled without sticking in hands. Reducing the amount of water could be done by spreading the soil and remixing it on any surface.

1.3. Clasification of soil
The main two systems of soil classification considered in the civil engineering are Unified Soil Classification System (USCS) and Classification of Soils for Highway Construction Purposes [10]. Both of these systems will be discussed in this study.

1.3.1. Unified Soil Classification System (USCS). The unified soil classification system, ASTM D2487 [11], was used to classify the soil as this system describes the classification of mineral and organomineral soils for engineering uses [12]. This system is the modified one of the Airfield classification system which is developed by Casgrande at the 1940s. If the precision is in demand while classifying the soil, particle size distribution characteristics and plasticity characteristics, liquid limit and plasticity index, are required. The fine-grained soil, silt and clay, is defined in the ASTM 421 [13] as that portion of soil passing sieve No.200 size (0.075 mm). The difference between clay and silt is that the clay in presence of water shows a respectable strength due to its plasticity characteristics when air-drying. Whilst, the silt has no strength or negligible strength when air-drying. Another difference between the clay and silt is that when drawing the point of intersection between liquid limit and plasticity index of clay on the plasticity chart, that point would be located above the A-line and the plasticity index of clay is greater than four. Conversely, in case of silt, the point of intersection will be located below the A-line and the plasticity index of soil would be less than 4, ASTM D2487 [11].

1.3.2. Classification of Soils for Highway Construction Purposes. Classification of soils for highway construction purposes, ASTM D3282 [14], was used to classify the soil as this system describes the classification of mineral and organomineral soils for engineering uses. This system classifies the soil into two main groups depending on the percent passing sieve No. 200 (0.075 mm). These two groups are granular materials group and silt-clay materials group. The first group, granular material, is divided into 3 groups, A-1, A-3, and A-2. The other group, silt-clay materials group, divides the soil into 4-subaltern groups, A-4, A-5, A-6, and A-7. If the precision is in demand while classifying the soil for highway construction uses, particle size distribution characteristics and plasticity characteristics, liquid limit and plasticity index, are required.

2. Materials and Soil Testing Method
All the soil samples in this study were carried out from almost all over Iraq country. The soils have wide-ranging physical properties and initial vision classification, but all soil samples were classified as fine-grained soils. The grain size distribution curves, following the ASTM D6913 [15] procedure, of all the soil samples used in this study are presented in figure 2. The samples were collected from Baghdad, the capital of Iraq, and cities located at different distances from Baghdad. As the target of

this study is evaluating the effect of the liquid and plastic limits on the soil classification, some samples were eliminated because they did not show any plasticity properties, non-plastic soils. As a result, nine soil samples from different cities, Baghdad, Anbar, Karbala, Diwanya, Samawa, Nassirya, Rumaitha, Basrah, and Hillah, were chosen to evaluate their properties in this study.

The weight of each soil sample was 4 Kg. these samples were brought from nine cities and each sample was divided into two parts and prepared as mentioned in the soil preparation section. Each sample divided into two specimens. One of these two specimen was tested based on air-dried method and the other specimen was tested based on the oven-dried method.

All results of the samples were analysed manually and using a software program to make sure the accuracy of obtained results. The software that is called Soil Tester, which is specialized in analysing soil tests results, was used to analyse the results. The software program interface can be shown in figure 3. The test procedure that were performed in this study followed the ASTM recommendations, as it has been aforementioned.

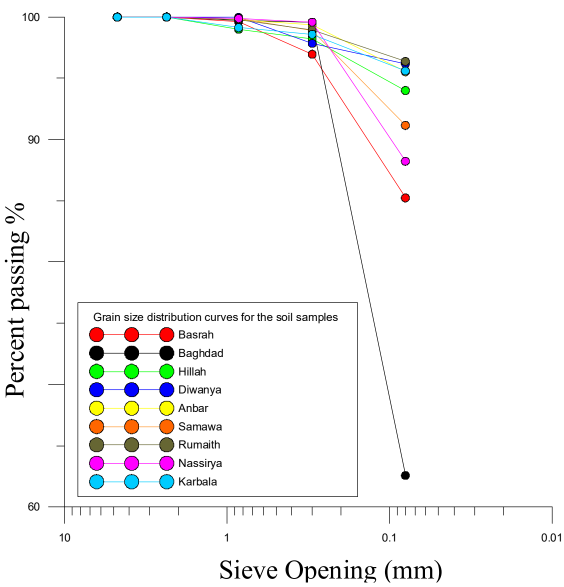

Figure 2. Grain size distribution curves for the soil samples used in this study.

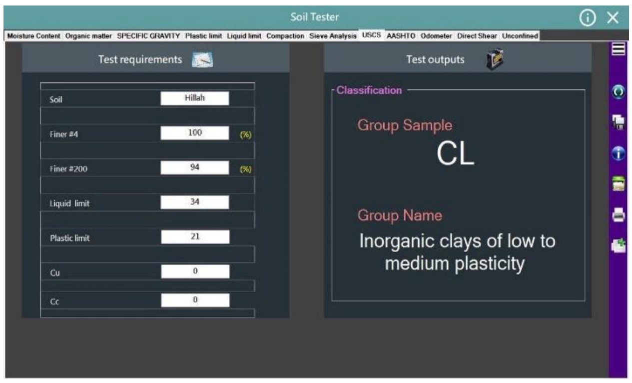

Figure 3. Soil tester program.

3. Results and Analysis

The effect of both soil-drying methods, oven dry and air dry, are discussed in following sections of this paper. Firstly, the influence of drying method on the soil consistency limits is analysed and then its effect on the soil classification.

3.1. Analysis of consistency limits for oven-dried and air-dried methods

All the Atterberg's test results were represented in table 1. The results showed that liquid limit of most oven-dried samples is higher than that of air-dried samples. Since, seven oven-dried samples have greater liquid limit and just two have less value of the liquid limit than air-dried samples. On the other hand, there is no Clear preference for the air or oven drying method regarding to the plastic limit results. Four oven-dried samples have greater plastic limit values. Whilst five air-dried samples have greater plastic limit values. All the results are presented in Radar charts to show the difference in the values. Figure 4 and 5 show the liquid and plastic limit results respectively based on the cities that have been taken from figure. 4 clarifies how the liquid limit values of oven-dried samples are greater than those of air-dried samples. Whilst figure 5 clarifies that, there is no clear correlation between plastic limit and the use of specific of the two methods of drying.

Table 1. Liquid and plastic limit for air and oven dried samples.

city	Coordinates		Liquid limit		plastic limit	
	latitude	longitude	oven dry	air dry	oven dry	air dry
Baghdad	33.340582	44.400876	26	25	15.81	19.38
Anbar	33.42056	43.307779	51.3	40	35.59	30.13
Hillah	32.463672	44.41963	34	28	21	23.8
Karbala	32.597902	44.016482	44.5	45.5	27.33	28.8
Diwanya	31.992886	44.925521	48	44	24.57	27.54
Samawa	31.305904	45.279884	38	36.5	28.5	25.51
Nassirya	31.057993	46.257262	26.8	27.2	22.51	22.7
Rumaitha	31.528454	45.203772	50	46	28.66	23.74
Basrah	30.533016	47.797466	35.2	34.2	30.64	27.64

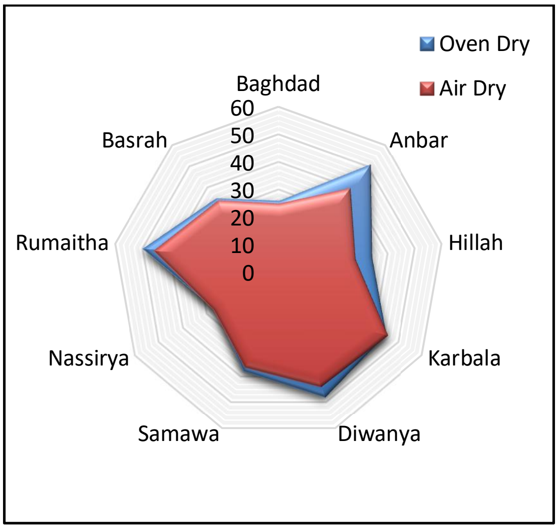

Figure 4. Liquid limit comparison of air and oven dried samples.

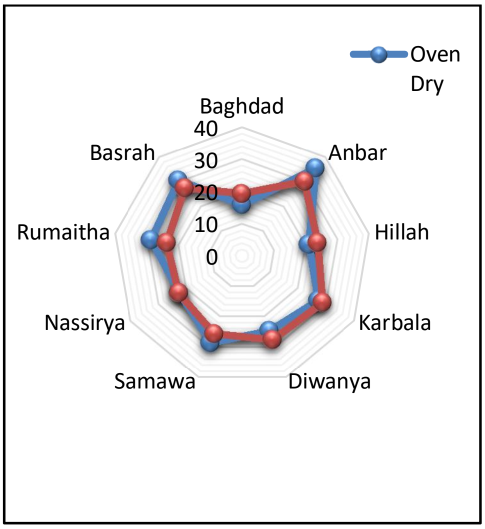

Figure 5. Plastic limit comparison of air and oven dried samples.

3.2. The effect of drying method on the soil classification

Soil classification due to unified soil classification system (USCS) and American Association of State Highway and Transportation Officials (AASHTO) system respectively were Presented in tables 2 and 3. Four of the samples exhibited similar classifications either oven-dried or air-dried. For example, the soil of Karbala, Diwanya, Samawa, and Nassirya were classified as CL, CL, CL, and CL-ML respectively for both methods of drying.

However, five samples showed different classifications due to the method of drying. For instance, Baghdad, Anbar, Rumaitha, Basrah, and Hillah have been classified as CL, MH, CH, ML, and CL, respectively if oven was used to dry the soils. On the other hand, these samples have been classified as CL-ML, CL, CL, CL-ML, and ML, respectively if the samples were exposed to weather temperature and dried naturally. Now it could be said that replacing the air-drying method with oven-drying method to speed up the drying process would give different classification results.

The classification results of the nine samples according to AASHTO classification system for both methods of drying were represented in table 3. The results showed that five of nine of samples have got different groups when dried by different methods. For example, Baghdad, Anbar, Karbala, Samawa, and Hillah have been classified under the groups A-6, A-7-5, A-7-6, A-4, and A-6 respectively when samples were dried using oven. Whilst these samples have been classified as A-4, A-4, A-7-5, A-6, and A-4 respectively when the soils samples were dried naturally. These results confirm that there is no possibility to replace the natural drying method by weather temperature with the oven drying method without changing in the classification accuracy. Both the two ways of classification, USCS and AASHTO, exhibited a match in the classification groups regarding the two drying methods.

On the contrary, there is no any effect of the method of drying on the value of group index GI, but this is not a significant point to be focused on, as the group index is just a number to modify the classification obtained from the procedure specified by ASTM D3282 – 09. The group index in a number gives a prediction whether the soil is suitable to be used as a highway subgrade or not, Das 2013. Table 4 represents the values of the group index for all soil samples for both methods of drying. While table 5 clarifies how these numbers, classify the soil as a highway subgrade material.

Table 2. Classifying the sample due to USCS.

(a) oven dried

city	percent finer sieve # 4	percent finer sieve # 200	Oven Dry			
			L.L	P.L	P.I	USCS
Baghdad	100	62.56	26	15.81	10.19	Sandy Lean Clay CL
Anbar	100	95.54	51.3	35.59	15.71	Elastic Silt MH
Karbala	100	95.6	44.5	27.33	17.17	Lean Clay CL
Diwanya	100	96.2	48	24.57	23.43	Lean Clay CL
Samawa	100	91.15	38	28.5	9.5	Lean Clay CL
Nassirya	100	88.22	26.8	22.51	4.29	Silty Clay CL-ML
Rumaitha	100	96.37	50	28.66	21.34	Fat Clay CH
Basrah	100	85	35.2	31.64	3.56	Silt with Sand ML
Hillah	100	94	34	21	13	Lean Clay CL

(b) air dried

city	percent finer sieve # 4	percent finer sieve # 200	Air Dry			
			L.L	P.L	P.I	USCS
Baghdad	100	62.56	25	19.38	5.62	Sandy Silty Clay CL-ML
Anbar	100	95.54	40	30.13	9.87	Lean Clay CL
Karbala	100	95.6	45.5	28.8	16.7	Lean Clay CL
Diwanya	100	96.2	44	27.54	16.46	Lean Clay CL
Samawa	100	91.15	36.5	25.51	10.99	Lean Clay CL
Nassirya	100	88.22	27.2	22.7	4.5	Silty Clay CL-ML
Rumaitha	100	96.37	46	23.74	22.26	Lean Clay CL
Basrah	100	85	34.2	27.64	6.56	Silty Clay with Sand CL-ML
Hillah	100	94	28	24.1	3.9	Silt ML

Table 3. Classifying the sample due to AASHTO.

(a) oven dried

city	percent finer sieve # 10	percent finer sieve # 40	percent finer sieve # 200	Oven Dry			
				L.L	P.L	P.I	AASHTO
Baghdad	100	99.57	62.56	26	15.81	10.19	A-6
Anbar	100	99.35	95.54	51.3	35.59	15.71	A-7-5
Karbala	100	98.59	95.6	44.5	27.33	17.17	A-7-6
Diwanya	100	97.8	96.2	48	24.57	23.43	A-7-5
Samawa	100	98.86	91.15	38	28.5	9.5	A-4
Nassirya	100	99.59	88.22	26.8	22.51	4.29	A-4
Rumaitha	100	98.96	96.37	50	28.66	21.34	A-7-5
Basrah	100	96.97	85.23	35.2	30.64	4.56	A-4
Hillah	100	98.24	94	34	21	13	A-6

(a) air dried

city	percent finer sieve # 10	percent finer sieve # 40	percent finer sieve # 200	Air Dry			
				L.L	P.L	P.I	AASHTO
Baghdad	100	99.57	62.56	25	19.38	5.62	A-4
Anbar	100	99.35	95.54	40	30.13	9.87	A-4
Karbala	100	98.59	95.6	45.5	28.8	16.7	A-7-5
Diwanya	100	97.8	96.2	44	27.54	16.46	A-7-5
Samawa	100	98.86	91.15	36.5	25.51	10.99	A-6
Nassirya	100	99.59	88.22	27.2	22.7	4.5	A-4
Rumaitha	100	98.96	96.37	46	23.74	22.26	A-7-5
Basrah	100	96.97	85.23	34.2	27.64	6.56	A-4
Hillah	100	98.24	94	28	23.8	4.2	A-4

Table 4. Group Index (GI) values for all soil samples.

city	Oven Dry		Air Dry	
	G.I	Subgrade Value	G.I	Subgrade Value
Baghdad	5.588	Poor	5.512	Poor
Anbar	12.544	V. Poor	8	V. Poor
Karbala	11.768	V. Poor	11.78	V. Poor
Diwanya	14.972	V. Poor	11.384	V. Poor
Samawa	8	Poor	8.396	Poor
Nassirya	8	Poor	8	Poor
Rumaitha	14.536	V. Poor	14.104	V. Poor
Basrah	8	Poor	8	Poor
Hillah	9.2	Poor	8	Poor

Table 5. Group Index and subgrade values.

Group Index (GI)	0	0-1	2-4	5-9	10-20
Subgrade value	Excellent	good	fair	poor	v.poor

4. Conclusion

Liquid and plastic limit tests were conducted on nine fine-grained soils collected from nine Iraqi cities. The aim of the study is to evaluate how the method of drying, oven and air-drying methods, could affect the liquid and plastic limit and then the classification of soil. Depending on the results and the analysis of these tests, it can be concluded:

- Soil classification systems, USCS and AASHTO, of fine-grained soils depends entirely on liquid limit, plastic limit, plasticity index, and grins size in addition to the group index which is consider as a modification factor for AASHTO classification system.
- The results showed that liquid limit of most oven-dried samples is higher than that of air-dried samples. Since, seven oven-dried samples have greater liquid limit and just two have less values of the liquid limit than air-dried samples.
- There is no Clear effect of the drying method on the plastic limit results. Since, four oven-dried, samples have greater plastic limit values. Whilst five air-dried samples have greater plastic limit values.
- Four of the samples exhibit similar classifications due to USCS either oven-dried or air-dried. For example, the soil of Karbala, Diwanya, Samawa, and Nassirya are classified as CL, CL, CL, and CL-ML respectively for both methods of drying. Whilst five samples show different classifications respect to the method of drying.
- The results show that five of nine of samples have different groups when classified due to AASHTO classification system regarding to the method of drying and the other four samples get same classification groups whether oven or air-dried.
- Both USCS and AASHTO exhibit a match in the classification groups regarding the two drying method with a possibility of less than 45%. Whilst 55% possibility show mismatch between the classification when air-drying method is used and that of oven drying method.
- There is no any effect of the method of drying on the value of group index GI, but this is not a significant point to be focused on, as the group index is just a number to modify the classification obtained from the procedure specified by ASTM D3282 – 09.
- It is elicited that replacing the air-drying method with oven-drying method to speed up the drying process if strictly forbidden.

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