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Liquid limit determination of various sand clay mixtures by Casagrande and fall cone test methods

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Abstract

This study aims to evaluate the liquid limit of various sand-clay mixtures obtained from both Casagrande and fall-cone test. Two types of clay (bentonite/kaolinite) were mixed with quartz and fine sand (FS) at mixture ratios of 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% by dry weight. The results indicated that fall cone penetration was governed by the water content of sand-clay mixtures. Cone penetration of sand decreased with 30% kaolinite addition whereas then increased interval between 30% to 100% kaolinite, but for bentonite, it increased from 0% to 100% bentonite content at constant water contents. Different equations between Casagrande and fall cone tests were proposed for different mixture types. Liquid limit values for both methods were found to be greater for bentonite-sand mixtures that kaolinite-sand mixtures.

Keywords: *Sand-clay mixtures, fall cone test, Casagrande test, liquid limit.*

Düşen koni ve Casagrande deneyleri ile çeşitli kum-kil karışımlarında likit limit hesaplaması

Özet

Bu çalışma, hem Casagrande hem de düşen koni deneylerinden elde edilen çeşitli kum-kil karışımlarının likit limit değerlerini değerlendirmeyi amaçlamaktadır. İki tür kil (bentonit / kaolin) 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, ve100% karışım oranlarında kuvars ve ince kum (FS) ile kuru ağırlıkça karıştırılmıştır. Sonuçlar, koni batma miktarının, kum-kil karışımlarının su içeriği tarafından

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yönetildiğini göstermiştir. Kumun koni penetrasyonu % 30 kaolin ilavesine kadar azalırken, daha sonra% 30 ila% 100 kaolin arasında artmıştır, ancak bentonit için % 0'dan% 100'e kadar bentonit içeriği ile artmıştır. Farklı karışım türleri için Casagrande ve düşen koni deneyleri arasında farklı denklemler önerilmiştir. Likit limit değerlerinin, bentonit-kum karışımları için, kaolin-kum karışımlarının daha yüksek olduğu bulunmuştur.

Anahtar kelimeler: *Kum kil karışımları, düşen koni deneyi, Casagrande deneyi, likit limit*.

1. Introduction

The liquid limit values of the soils are the water content requires making soil liquid. The increasing water content makes soil from dry state to solid, semi-solid, plastic and liquid state, respectively. Atterberg [1] described these states and the water contents separating them. As the soil becomes liquid from solid state, the strength decreases while the ability to give soil a shape (plasticity) increases. The liquid limit is defined as the specific water content separates the liquid state from the plastic state. It is necessary to know the liquid limit value because of the reduction of resistance in the liquid range of the soil.

The liquid limit values of the soil can be obtained by Casagrande and fall cone test methods. Casagrande is an experiment to measure the strength of the soil against stroke of Casagrande apparatus. In the Casagrande experiment, water content corresponding to 25 strokes is regarded as the liquid limit of soil tested. The fall cone experiment is based on the resistance of the soil against the fall cone penetration. In the fall cone test, the water content corresponding to 20 mm penetration was accepted to be the liquid limit of the soil.

There are various studies related to the reference of the liquid limit values found from fall cone and Casagrande test methods [2-5]. For example, Hrubesova [3] compared the liquid limit values of loam and sodium bentonite obtained from both fall cone and Casagrande tests. The results show that the fall cone and Casagrande liquid limit values are very close for medium plasticity loam, whereas in the sodium bentonite experiments liquid limit values from Casagrande test are higher than those from fall cone test. Chistaras [2] showed that the liquid limit values found in the fall cone test method are slightly higher than those examining by Casagrande test. Spagnoli [4] also concluded that the fall cone liquid limit was slightly higher than the Casagrande liquid limit in experiments performed on kaolinite and illitic clays. A similar result obtained from Di matteo [5]. Shinavi [6] stresses that the two methods gave very close values in the test method on clayey soils (Figure 1). The liquid limit values found in the fall cone test are higher than the Casagrande test, as evidenced by the literature results [2, 4, 7].

In this study, two different clays having different plasticity values (bentonite and kaolinite) were mixed with sand with mixture ratios ranging from 0% to 100%. Two different sands (quartz and fine sand) were used for each mixture. The liquid limit values of the mixtures are compared with both the Casagrande and fall cone test methods. Different formulas have been proposed for mixtures of sand with kaolinite and bentonite clay.

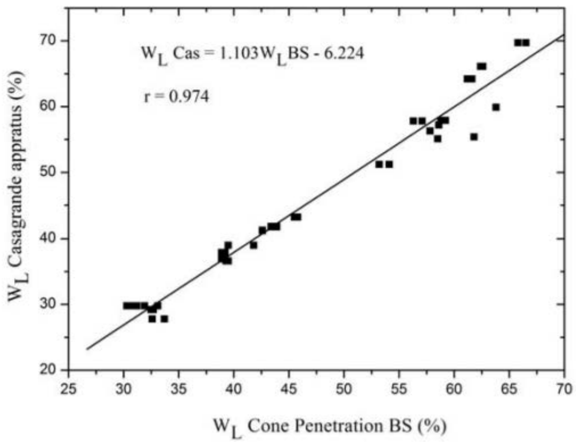

Figure 1. Liquid limit values comparison for fall-cone and Casagrande experiments [6].

2. Materials

Bentonite and kaolinite were mixed with two different sands with mixtures ratio ranging among 0% to 100%. The chemical analysis results of these commercially available materials are given in Table 1. The specific gravity of quartz was found to be 2.65. Some geotechnical properties of quartz sand along with sieve analysis is given in Figure 2. Two types of clay used in the experimental study are commercially available bentonite and kaolinite. The mixtures were dried in the oven for 24 hours at 105°C before mixing. In Casagrande test, according to ASTM D4318 [8], the samples were dried and a sample was taken from all the mixtures and sieved through No.40 sieve (0.425 mm). The liquid limit of the mixtures was determined as the water content corresponding to 25 strokes. Fall cone tests were carried out according to BS 1377 [9] using a British fall cone apparatus. Water content corresponding to 20 mm penetration is recorded as the liquid limit of the specimen.

Table 1. Chemical analyses of materials used during this study.

Minerals	Bentonite (%)	Quartz (%)	Kaolinite (%)
A.Z	7.5	0.2	0
$Sİ O_2$	71	99.2	47
AL_2O_3	14	0.5	32
FE_2O_3	0.7	0.03	0.6
$Tİ O_2$	0.05	0.02	0.8
CAO	1.1	0.02	0.6
MGO	3.2	0.02	0
NA_2O	0.25	0.1	0
K_2O	1	0.02	0
LoI	0	0	13
SO_3	0	0	0.3

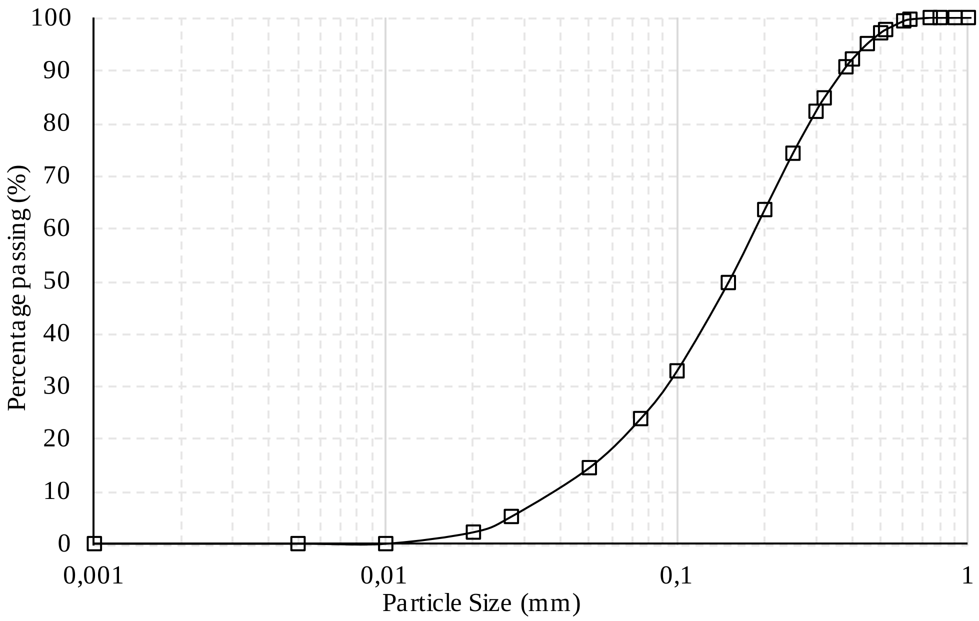

Figure 2. Particle size distribution of quartz sand.

3. Results and discussions

The fall cone test seems to offer a more accurate and reproducible method for determining simultaneously both the liquid and plastic limits. Shimobe [10], proposed the simultaneous determination of these consistency limits termed the 'extended fall cone method using the various cone types, and verified its validity based on experimental data with a wide range of soil type and plasticity. According to this method, the relationship between cone penetration d and water content w is given in terms of a power trend line function transformed to fall cone penetration - water content (log to log) graph plot as;

$$\omega = C_0 * d^{\beta} \tag{1}$$

After each regression analysis as equation 1 was performed to mixtures in fall-cone penetration-water content graphs, the liquid limit and plastic limit values were estimated using equations 2 and 3. The fall cone liquid limit (w_{LC}) and the fall cone plastic limit (w_{PC}), are obtained from equation 1 and penetration values corresponding to d_{LL}=20 mm and d_{PL}=2 mm, respectively.

$$\omega_{LC} = C_0 * (20)^{\beta} \tag{2}$$

$$\omega_{PC} = C_0 * (2)^{\beta} \tag{3}$$

Figure 3 and figure 4 shows the fall cone penetration - water content relationship obtained from equations (2) and (3) based on the recent experimental results.
Fall cone penetration-water content relationship is shown for quartz- kaolinite and quartz-bentonite mixtures in Figure 3a and Figure 3b, respectively. Figure 3a shows that the penetration values are reduced up to 30% kaolinite content, beyond this content it is

increased at constant water content. This behavior indicates that threshold fines content (FC_t) is encountered in the fall cone experiment. FC_t can be defined as the content of the fine grain that changes the behavior of the soil. The case for fine content smaller than FC_t; sand grains contact points manages the main behavior of mixtures [11]. The case for fines content exceeds to FC_t clay particles governed the main behavior of mixtures. In this study kaolinite and bentonite considered as fine materials and quartz also considered as a coarse material. In bentonite-quartz mixtures (Figure 3b), the bentonite additions decreased the penetration values of mixtures at a constant water content.

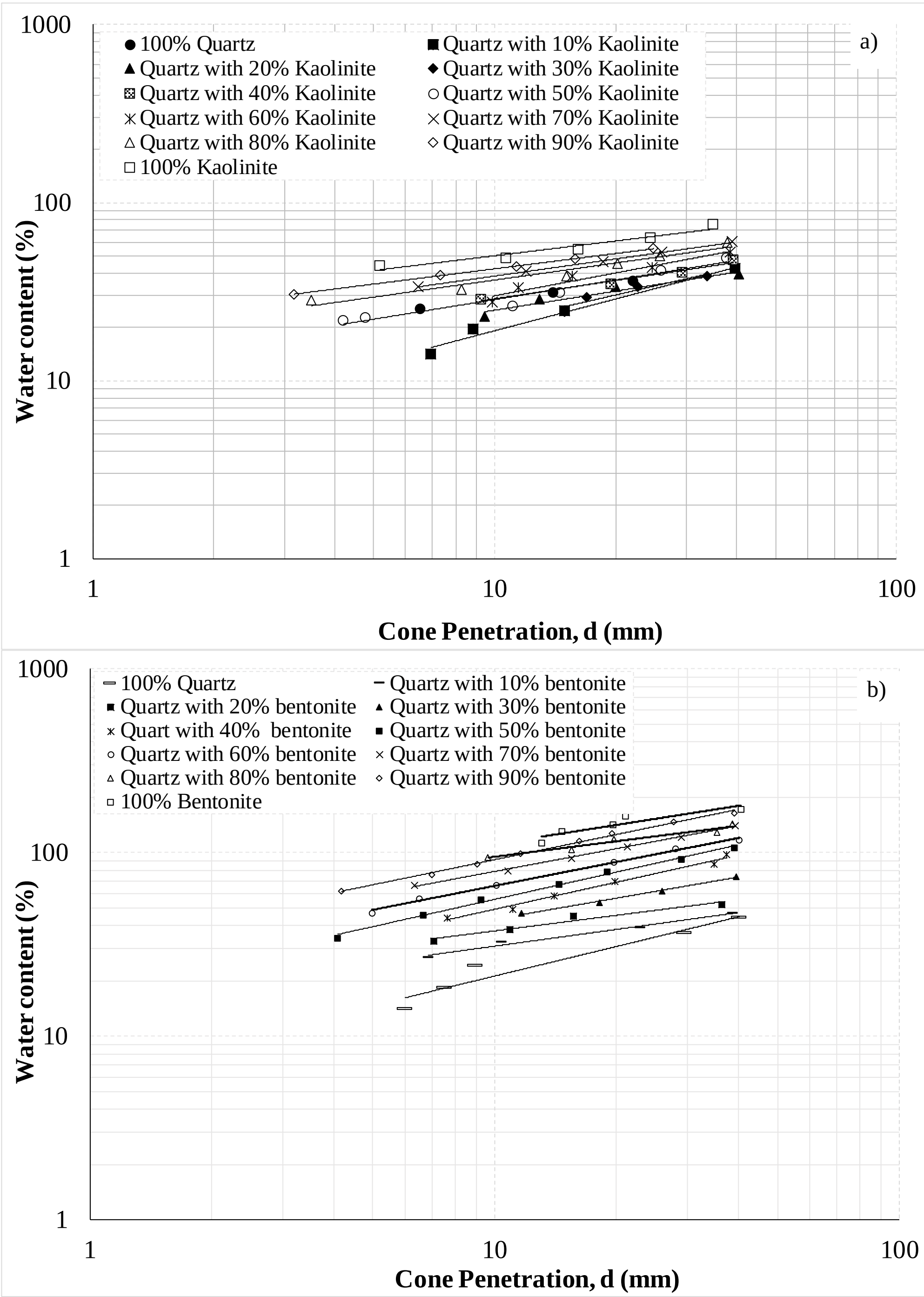

Figure 3. Variation of penetration with water content for the a) quartz with various kaolinite, b) quartz with various bentonite.

Figure 4a, 4b shows water content-penetration relation of FS-kaolinite mixtures. The mixture with %100 bentonite has lowest penetration value at constant water contents. In addition, both figures indicated that FC_t seems to be 10% of clay.

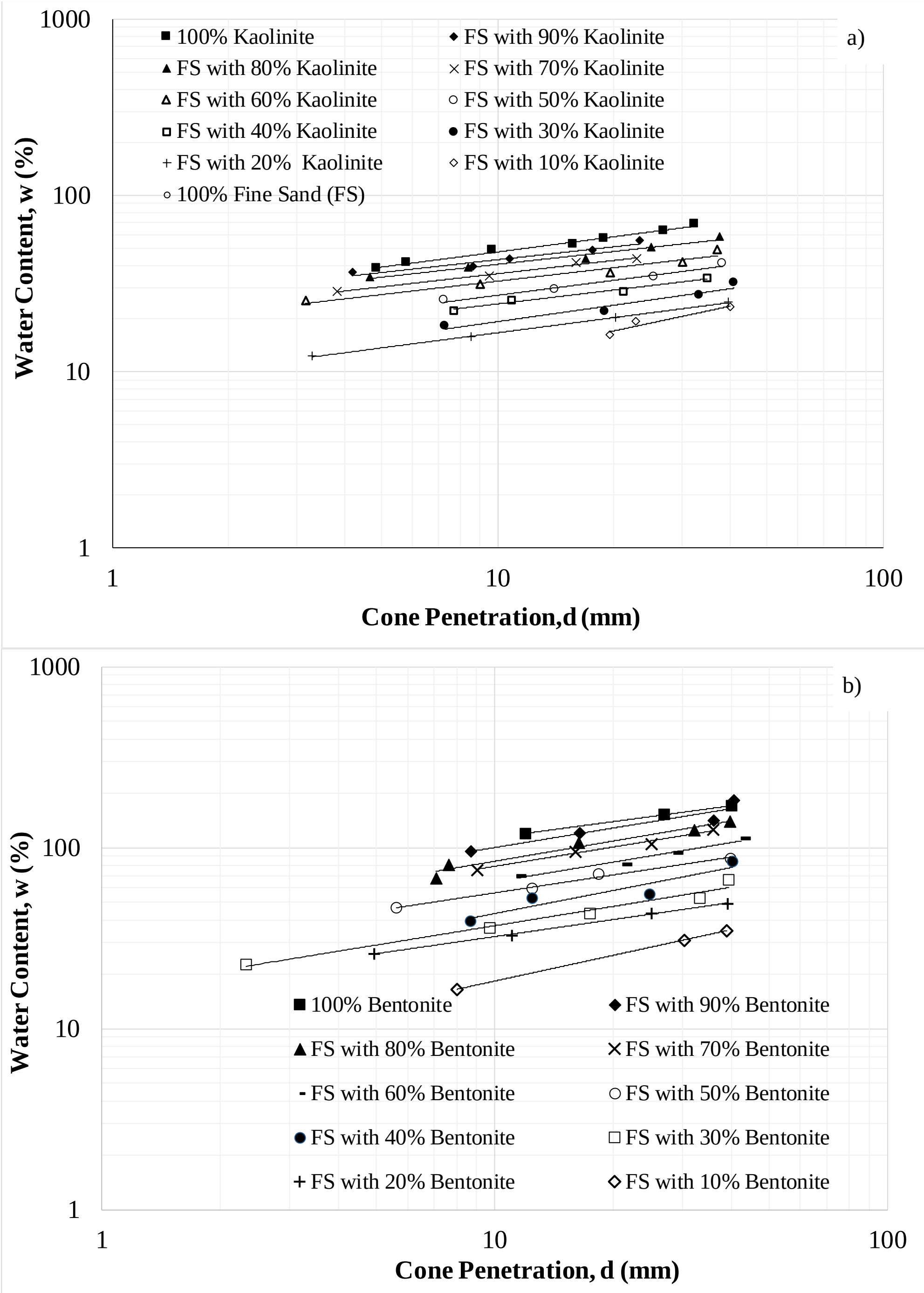

Figure 4. Variation of penetration with water content for the a) fine sand with various kaolinite, b) fine sand with various bentonite.

In this research, the liquid limits were determined using equation 2. The important factors affecting the Atterberg limits of soil are grain-size distribution of soils, clay shapes, specific surface area, bentonite-kaolinite content. Figure 5 shows the variation of the liquid limit values with bentonite and kaolinite additives. As can be seen clearly from the figure, the liquid limit increases as the clay content increased. This result has also been observed by many studies [12, 13]. This behavior is reasonable due to an increase of fine grains with the addition of clay particles. Liquid limit estimate as a function of kaolinite and bentonite content regressions were given in Figure 5. When the granular material increases, the w_L decreases. From the Figure 5, it is also clear that mixtures including quartz has the greater water content that those including FS at a constant bentonite/kaolinite content. This behavior proves that water adsorption of quartz particles are higher than FS.

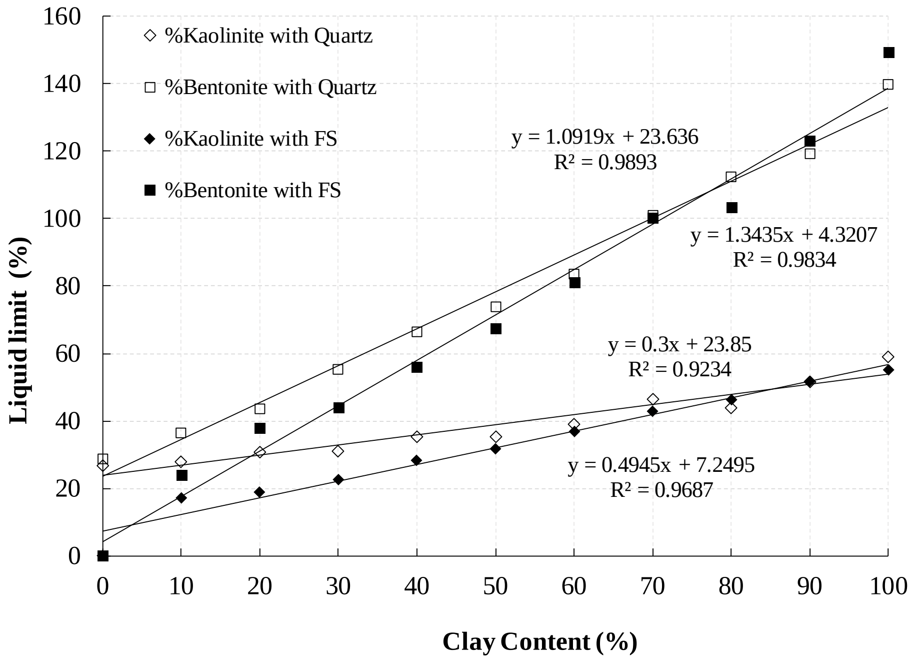

Figure 5. Liquid limit values as a function of clay content.

It is clear in the literature that close relationships observed between the fall cone and Casagrande experiments [2-5]. The liquid limit values obtained from the fall-cone and the Casagrande test are compared in Figure 6. In this study, a close relationship was also observed for samples tested. The regression analysis having the high coefficient of determination (R^2) values were found as follows;

$w_{LC} = 0.961 * w_L + 0.3017$ ($R^{2=}$ 0.838) (4)

$w_{LC} = 0.8014 * w_L + 11.251$ ($R^{2=}$ 0.9854) (5)

$w_{LC} = 0.8122 * w_L + 4.73$ ($R^{2=}$ 0.9593) (6)

$w_{LC} = 0.8555 * w_L + 4.325$ ($R^{2=}$ 0.9601) (7)

Testing results clearly showed that Casagrande liquid limit values are higher than fall-cone liquid limit values for quartz-bentonite mixtures. This could be higher plasticity of bentonite. The similar results were seen in the several researches. For instance, Hrubesova [3] compared the liquid limit values of loam and sodium bentonite obtained from both fall cone and Casagrande tests. Their results showed higher liquid limit values in Casagrande test than the fall cone test in the mixtures including high plastic sodium bentonite. As for mixtures with kaolinite generally, fall cone liquid limit found to be greater than those with bentonite. As a similar result, Spagnoli [4] concluded that the fall cone liquid limit was slightly higher than the Casagrande liquid limit in experiments performed on kaolinite and illicit clays. As a result, both Casagrande and fall-cone test showed close relationships whereas there could be a little different depending on plasticity values of materials. In the literature, many studies found that close reasonable relationships for both test methods [2, 4, 7]. At similar clay contents, the variation of the liquid limit values was obtained for different sand-clay mixtures.

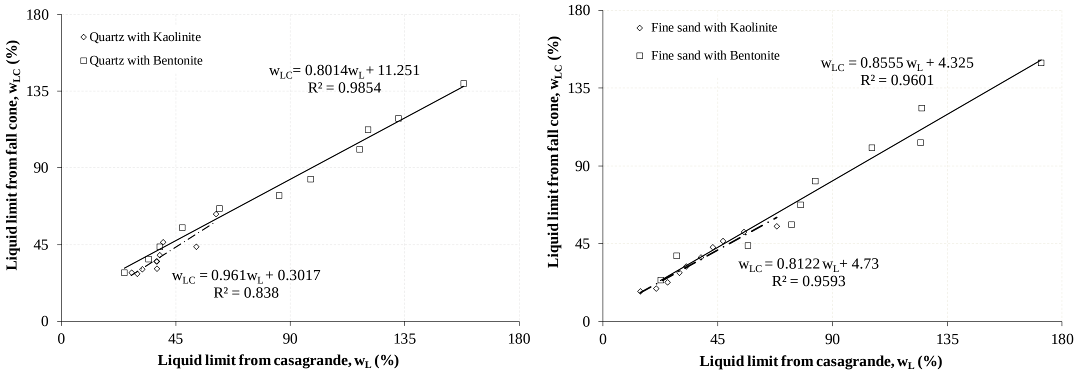

Figure 6. Comparison of liquid limit values obtained from both Casagrande and fall cone test for two types of clay (kaolinite, bentonite) with a) quartz, b) fine sand.

At present the liquid limit and the plastic limit of soils are determined by two completely different methods. Many studies had been done to determine the plastic limit indirectly from the fall cone tests [15-16]. If fall cone tests were to be available for the plastic limit as well as the liquid limit, then the two tests might become easier, more useful and more meaningful mechanically. Figure 7 shows the comparison of plastic limits determined by conventional and fall cone methods. According to this figure, through the correlation of fall cone plastic limits has a little scatter in comparison with the case of conventional plastic limits. The equation was found to be as follow;

$$W_{pc}=1.0009_{Wp}-3.1889 \quad (8)$$

The results were found to be consistent with the literature [10-14].

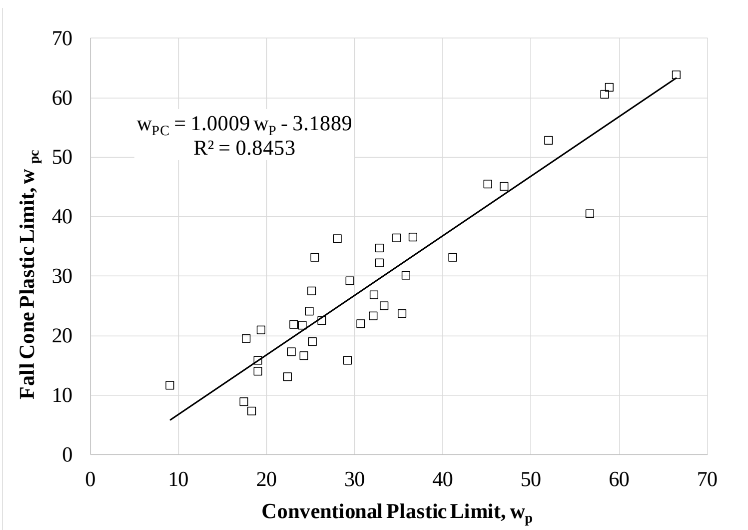

Figure 7. Comparison of plastic limits by the conventional and fall cone methods.

As an index that represents the state quantity of soils at present, a liquidity index I_L has been often used. The liquidity index I_{LC} determined from the extended fall cone test of soils is uniquely related with the cone penetration through equations (1) to (3) as follows;

$$I_{LC} = \frac{\left(\frac{d}{d_{LL}}\right)^{\beta} - \left(\frac{d_{PL}}{d_{LL}}\right)^{\beta}}{1-\left(\frac{d_{PL}}{d_{LL}}\right)^{\beta}} \tag{9}$$

In this study, the average value of the β=0.30 is found. Therefore, in case of using fall cone, equation (9) is given as;

$$I_{LC} = \frac{\left(\frac{d}{20}\right)^{0.3} - (0.1)^{0.3}}{1-(0.1)^{0.3}} \tag{10}$$

Figure 8 shows the relationship between cone penetration and liquidity index of soils, based on large number of data obtained by the researchers. As a result, it is understood from this figure that a unique log d-I_{LC} relationship of soils exists in irrespective of soil type, testing apparatus and operators.

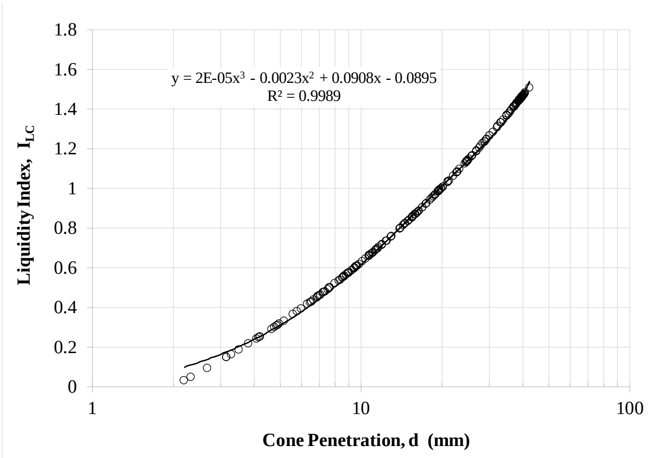

Figure 8. Relationship between cone penetration and liquidity index of soils.

4. Conclusions

In many countries, the fall cone test has been recommended as a definitive method than the Casagrande method for determination liquid limit. Moreover, according to many experimental studies, it was reconfirmed that the fall cone test can be used to calculate the plastic limit. From a large number of experimental results, it is concluded that fall cone test is a simple and reliable soil classification test for simultaneous determination of both liquid and plastic limits.

In this study, quartz was mixed with kaolinite and bentonite clays at various ratios. Fall cone and Casagrande experiments were performed on the mixtures and the liquid limit values obtained from them were compared. The following conclusions can be drawn in the present study;

- In the fall cone test, the penetration values are clearly governed by the water content.
- In the Fall cone experiment, the kaolinite ratio increased penetration up to 30% and then decreased afterwards. However, bentonite contents are continuously decreasing the penetration values.
- As both kaolinite and bentonite content increases, the liquid limit of the mixtures increases, whereas the liquid limit value of mixtures containing bentonite is higher than those containing kaolinite clay for a constant sand ratio.
- The liquid limit values obtained from the fall cone and Casagrande tests are consistent and close to each other. For quartz sand mixed with kaolinite and bentonite, formulas between fall cone and Casagrande liquid limit values are proposed.

As a result, the fall cone test is more useful and powerful tool for the practical soil classification test.

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