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Comparative study of Determination of Liquid limit by Percussion cup, Cone and Improved k_o-Stress Methods

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Abstract

Liquid limit is used extensively by geotechnical engineers to determine the characteristics of cohesive soils and also in preliminary assessment of their engineering properties related through correlations. The reported observation that the liquid limits obtained by the two widely used percussion and cone method differ quite appreciably from each other at low and high plasticity ranges indicates that the mechanisms dominating the two testing procedures are different. It has been suggested in the literature that cone method should be preferred for kaolinitic soils and percussion cup method for montmorillonitic soils. In the present study, liquid limit was determined by the two popular methods and Improved k_o-stress method for ten natural soils, five of them being essentially kaolinitic and the remaining montmorillonitic. From the results obtained, it is found that the liquid limit obtained by k_o –stress are observed to be in between percussion and cone method irrespective of the clay mineral type. In this method, both the viscous shear resistance and frictional shear resistance seems to work simultaneously and depending on the type of clay mineral being present in the soil, that particular mechanism dominates and becomes the controlling mechanism. Hence k_o –stress can be adopted for determining the liquid limit of fine grained soils irrespective of the clay mineral type being present in it.

KEY WORDS: clays, cohesive soils, geotechnical engineering, index property, compressibility

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Introduction:

It is well known that determination of liquid limit is very important, as it is used as a correlative parameter in a preliminary estimation of many physical and engineering properties and also for classification of fine-grained soils for various engineering applications through the plasticity chart. Though, many methods of determining this simple index parameter have been attempted by various researchers, only two methods have been popularly used, namely Casagrande's percussion cup method and cone penetration method. However, these methods suffer from inherent short comings. Also, the mechanisms controlling the determination of liquid limit by these methods being different, it is resulting in varied results for kaolinitic and montmorillonitic soils, which are present in natural soils in varying amounts. It has also been suggested by Sridharan and Prakash (1999) that cone method should be preferred for kaolinitic soils and percussion cup method for montmorillonitic soils.

To improve the method of determining liquid limit, several attempts have been made in the past to find alternate test methods to determine the liquid limit of soil, like the dye absorption method (Ramachandran et al., 1963); the vane shear method (Darienzo and Vey 1955) and the soil moisture tension method (Russel and Mickle 1970), Absorption water content and liquid limit of soils (Sridharan and Nagaraj, 1999), Equilibrium water content under ko stress (Sridharan et al., 2000), Determination of liquid limit from equilibrium sediment volume (Prakash and Sridharan 2002). Continuous research efforts are being made by various researchers to develop better and reliable methods to determine liquid limit. In this direction we have dual-weight fall cone method (Lee and Freeman 2009) and an improved k_o-stress method of determining liquid limit (Nagaraj and Sridharan-accepted for publication in 2010). The authors felt that there is some merit considering exploring how the liquid limit obtained by k_o-stress method would compare with that obtained by existing popular methods with respect to the mineralogical content of the natural soils.

This experimental investigation presents the results of the comparative study made on ten natural soils, five of them being essentially kaolinitic and the remaining montmorillonitic in nature, by adopting the existing two popular methods along with the newly proposed Improved k_o-stress method of determining liquid limit.

Comparison of Percussion Cup Method and Cone Penetration Method of determining liquid limit

The Percussion method of determining the liquid limit was designed and later modified by Casagrande (1932, 1958). In spite of its various limitations, it is still being adopted in many parts of the world. While the American standard prefers a device with hard base for testing (ASTM designation D 423-66, 1989), the British code specifies a device with soft base (BS: 1377-part 2, 1990). It has been observed by many (Norman 1958; Casagrande 1958; Whyte 1982, 1983) that the percussion method with the soft base always gives a higher value of liquid limit than that by the same method with the hard base.

Many have observed that the liquid limit values obtained by the percussion method and the cone method are not the same. Using the data of Wasti and Bezirci (1986), Sridharan and Prakash (2000) have reported that for the soils of lower plasticity, the cone method gives values higher than those by percussion method. For the soils of higher plasticity, the percussion method yields higher values and this deviation between the results from the two methods becomes appreciably more with the increase in the plasticity of the soil.

Recent study on the mechanisms controlling in the popular methods of determining liquid limit of soil

In a recent study Sridharan and Prakash (1999) describes in detail comparing the mechanisms controlling the limit of montmorillonitic and kaolinitic soils and showed that they are different. They also observed that, the liquid limits obtained by the conventional percussion cup method and the cone penetration method differ quite appreciably from each other at low and high plasticity ranges indicating that the dominating mechanisms in the two testing procedures are different. They hypothesised that the liquid limit obtained from the percussion

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method is primarily controlled by the viscous shear resistance and the cone method is essentially governed by the frictional shear resistance. Based on this hypothesis they could explain, in general, the observation that the percussion method gives higher liquid limit values for the montmorillonitic soils than the cone method and that the cone method gives higher liquid limit values than the percussion method for kaolinitic soils. This was validated using the results from the literature (Queiroz De Carvalho 1986) as well as from the results of their experimental investigation.

The observed difference between the liquid limits obtained by the two methods has been attributed to the type of clay mineral and its proportion in the clay content rather than the clay content alone. The clay mineral type and its proportion in the clay content decide which of the two methods gives higher liquid limit values than the other.

There is a good matching between the mechanism governing the liquid limit of montmorillonitic soils (i.e., the thickness of the diffuse double layer) and the dominant mechanism in the percussion method of testing (i.e., viscous shear resistance due to the diffuse double layer held water). Similarly, the mechanism governing the liquid limit of kaolinitic soils (i.e., the mode of particle arrangement and the shear resistance at the particle level) and the dominant mechanism in the cone method of testing (i.e., the frictional resistance at the particle level) match. Hence, greater accuracy can be achieved by using the percussion method for montmorillonitic soils and the cone method for kaolinitic soils.

Improved method of determining the liquid limit under k_o-stress

Sridharan et al., (2000) proposed k_o-stress method for determining the liquid limit of soils. Nagaraj and Sridharan (2010) have improved the same method with smaller size rings of 38 mm (Fig.1) instead of 60 mm. This improved method with respect to the size of the rings has found to be convenient for routine practice. This method has been adopted for this present study along with the two popular methods.

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Material and methods:

Ten natural soils, five of them being essentially kaolinitic and the remaining five of them montmorillonitic soils, obtained from various geological locations of Karnataka were selected and used in the present study. The soils were characterized for their physical properties as specified by ASTM standards (excepting liquid limit) as summarised in Table 1.

The specific gravity of soils used was determined using a pyconometer (stoppered bottle having a capacity of 50 ml) as specified by ASTM Standard Test Method for Specific Gravity of Soils (D 854-92, 1995). The specific gravity values are an average of three tests; individual determinations differed from the mean by less than 0.01.

The plastic limit of soil specimens were determined by 3mm rolling thread method as outlined in the ASTM Standard Test Method for Liquid Limit, Plastic limit, and Plasticity Index of Soils (D 4318 – 93, 1995). The plastic limit values are an average of 3 trials.

The shrinkage limit of soil specimens were determined by procedure as outlined in the Standard Test Method for Shrinkage Factors of Soils by the Mercury Method (D 427 – 04, 1995). The shrinkage limit values are an average of three trials.

Grain size analysis was done according to ASTM Test Method for Particle Size Analysis of Soils (D 422-63, 1995) by wet sieving of 300 g of dry soil using a 75µm sieve. The portion retained on the 75µm sieve was oven dried and sieved using sieves of 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 425 µm, 300 µm, 212 µm, 150 µm and 75 µm sizes. The soil passing 75µm was collected carefully and air-dried, and the grain size distribution analysis was performed by the hydrometer method. The results are presented in Table 1.

The liquid limit of the soils was determined by the Cone Penetration method as specified by BS: 1377 – part 2, 1990 and IS: 2720-Part 5, 1985; and Percussion cup method as specified by BS: 1377-part 2, 1990 **(Soft base)**. The liquid limit tests were carried out to obtain a minimum of five points for plotting

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the flow curve. The consistency of soil specimen was adjusted such that the number of blows in the percussion cup method **(Soft base)** was between 10 and 40; and by cone penetration method, the cone penetration ranged between 15mm and 25 mm.

The liquid limit by k_o-stress method was conducted as suggested by Nagaraj and Sridharan (2010). For convenience and clarity of presentation, the data on liquid limit obtained by the three methods adopted in this study has been presented in Table 2.

Results and discussion

Figs. 2 (a) to (c) show the typical liquid limit plots for a kaolinitic soil (Soil No.4) by Casagrande's Percussion cup method, Cone method and Improved k_o-stress method respectively. Similarly Figs. 3 (a) to (c) show the typical liquid limit plots for a montmorillonitic soil (Soil No.7) respectively by the three methods mentioned above. The results of the liquid limit obtained by the three methods adopted in the present study for all the ten soils used has been summarized in Table 2. Fig. 4 is plot of liquid limit by cone method versus Percussion cup method for both the kaolinitic and montmorillonitic soils used in the present study. It can be seen that for kaolinitic soils cone method gives higher values of liquid limit as compared to that of Percussion cup method and vice versa is true for montmorillonitic soils. This is similar to that reported by Sridharan and Prakash (1999). However, it can be observed from the Table 2 that the values of liquid limit obtained by k_o-stress method have remained in between that obtained by Percussion cup and cone methods irrespective of the soil type and thus has not shown any diabolic influence of the clay mineral on the liquid limit of soils. Fig. 5 is a plot of the average value of liquid limit obtained by Percussion cup and cone methods versus the liquid limit obtained by k_o-stress method, wherein a good relation is found between the plotted parameters.

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Proposed mechanisms in k_o –stress method of determining liquid limit

From the above findings, it is felt by the authors that in the k_o –stress method of determining liquid limit, both the viscous shear resistance and frictional shear resistance work simultaneously. Depending on the type of clay mineral being present in the soil, that particular mechanism dominates and becomes the controlling mechanism. Further, it is better to define liquid of a soil based on stress rather than based on strength as being currently adopted in the popular methods. Thus, the water content of the soil slurry which equilibrates under the influence of the external k_o –stress (0.9 kPa) can be better defined as the liquid limit water holding capacity of soil. Hence this method can be adopted for determining the liquid limit of fine grained soils irrespective of the clay mineral type being present in it.

Influence of value of liquid limit on the soil classification

Figs. 6 (a) and (b) show the position of the soil on the plasticity chart for kaolinitic soils (soils 1 to 5) and montmorillonitic soils (soils 6 to 10) respectively. The nomenclature of the ten soils as obtained by the three methods adopted in this study have been tabulated in Table 3. It can be seen that for some soils the nomenclature has changed with the variation in the liquid limit obtained by the two popular methods, but not by k_o –stress. This can have a wrong inference on the engineering behaviour of soils. For example for soil No.5, which is classified as Clay of Intermediate compressibility (CI) by both cone and k_o-stress method, whereas the soil is classified as Clay of High Compressibility, which is a misleading information in interpreting the behaviour of soil. Further the values of the engineering properties obtained through the correlation equations relating liquid limit or the indices will also be misleading.

Conclusions

Though liquid limit is a very extensively determined index property in routine practice by geotechnical engineers, its determination has been a question due to the observed variation with the method adopted. The two widely used

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percussion and cone method have found to have different controlling mechanisms and hence the observed variation in the liquid limit values at low and high plasticity ranges. It has also been suggested in the literature that cone method should be preferred for kaolinitic soils and percussion cup method for montmorillonitic soils. Results from this experimental investigation done on ten natural soils, five of them being essentially kaolinitic and the remaining montmorillonitic indicate that the liquid limit obtained by k_o –stress are observed to be in between percussion and cone method irrespective of the clay mineral type present in the soil. In this method both the viscous shear resistance and frictional shear resistance seems to work simultaneously and depending on the type of clay mineral being present in the soil, that particular mechanism dominates and becomes the controlling mechanism. Hence this method can be adopted for determining the liquid limit of fine grained soils irrespective of the clay mineral type being present in it.

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Table 1 - Physical properties of soil used in the present study

Soil. No	Soil Description	Gs	w_P (%)	w_S (%)	Grain Size distribution				Clay Minerology
					Gravel (%)	Sand (%)	Silt (size) (%)	Clay (size) (%)	
1	Red Earth - 1, Ragigudda, Bangalore	2.70	14.5	14.8	0	45	47	8	Kaolinite
2	Red Earth - 2, Tumkur	2.69	19.8	18.7	0	46	42	12	Kaolinite
3	Red Earth - 3, Yelahanka, Bangalore	2.67	19.9	15.8	0	28	60	12	Kaolinite
4	Red Earth - 4, Bommasandra, Bangalore	2.65	34.3	16.8	0	38	58	4	Kaolinite
5	Red Earth - 5, Kanakapura	2.66	24.1	14.2	0	46	47	7	Kaolinite
6	Black cotton - 1, Chennagiri	2.70	27.2	8.5	0	19	43	38	Montmorillonite
7	Black cotton - 2, Hungunda	2.71	33.1	8.5	0	14	45	41	Montmorillonite
8	Black cotton - 3, Raichur	2.69	26.2	9.8	0	2	56	42	Montmorillonite
9	Black cotton - 4, Belgaum	2.71	37.9	11.1	0	4	27	69	Montmorillonite
10	Black cotton - 5, Chitradurga	2.70	38.9	9.8	0	12	25	63	Montmorillonite

Table 2 – Liquid Limit obtained by Casagrande's Percussion Cup method, Cone

Soil No	Liquid limit, w_L (%)		
	Casagrande's Percussion Cup method	Cone Penetration method	k_o-Stress method
1	29.8	31.5	30.2
2	34.6	38.5	35.1
3	37.8	40.0	38.4
4	45.0	48.1	46.0
5	47.6	50.4	48.3
6	55.5	53.3	54.5
7	63.5	60.9	62.0
8	68.9	67.8	68.2
9	75.6	72.4	73.8
10	88.4	83.3	87.1

Penetration method and k_o- Stress method for soils used in the present study

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Table 3 - Classification of Soils used in the present study by using liquid limit obtained by various method

Soil No	W_L			W_P	I_P			Soil Classification#		
	Casagrande's Percussion Cup Method	Cone Penetration Method	k_o-Stress Method		Casagrande's Percussion Cup Method	Cone Penetration Method	k_o-Stress Method	Casagrande's Percussion Cup Method	Cone Penetration Method	k_o-Stress Method
1	29.8	31.5	30.2	14.5	15.3	17.0	15.7	CL	CL	CL
2	34.6	38.5	35.1	19.8	14.8	18.7	15.3	**CL**	**CI**	**CI**
3	37.8	40.0	38.4	19.9	17.9	20.1	18.5	CI	CI	CI
4	45.0	48.1	46.0	34.3	10.7	13.8	11.7	MI	MI	MI
5	47.6	50.4	48.3	24.1	23.5	26.3	24.2	**CI**	**CH**	**CI**
6	55.5	53.3	54.5	27.2	28.3	26.1	27.3	CH	CH	CH
7	63.5	60.9	62.0	33.1	30.4	27.8	28.9	MH	MH	MH
8	68.9	67.8	68.2	26.2	42.7	41.6	42.0	CH	CH	CH
9	75.6	72.4	73.8	37.9	37.7	34.5	35.9	MH	MH	MH
10	88.4	83.3	87.1	38.9	49.5	44.4	48.2	**MH**	**MH-CH**	**MH-CH**

As per AS 1726-1993 and IS 1498-1970

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LIST OF FIGURES

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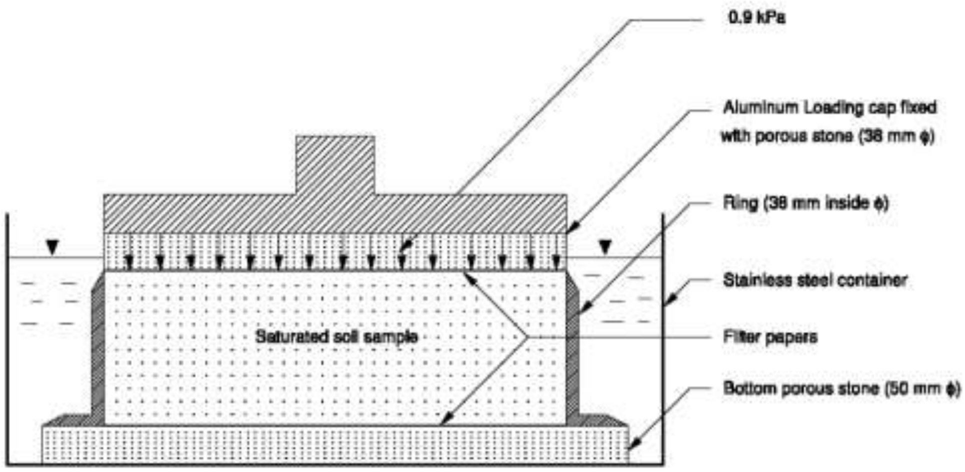

Fig1. Diagrammatic representation of the apparatus used to determine liquid limit by the Improved k_o-stress method (Nagaraj and Sridharan 2010)

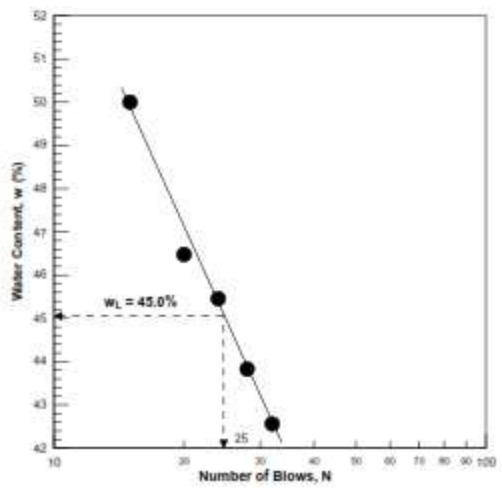

Fig 2 (a) – Liquid limit for by Casagrande's method for Kaolinitic soil (Soil No. 4).

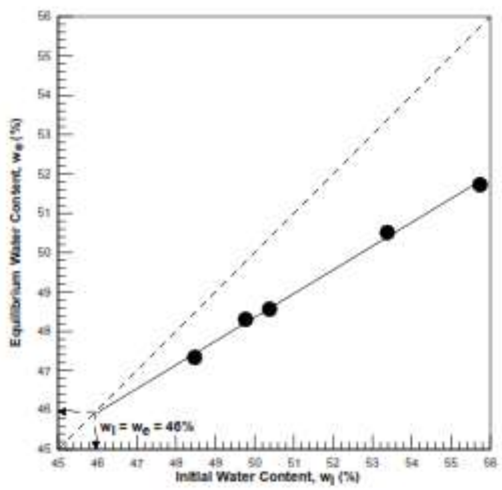

Fig 2 (b) - Liquid limit by Cone Penetration method for Kaolinitic soil (Soil No. 4).

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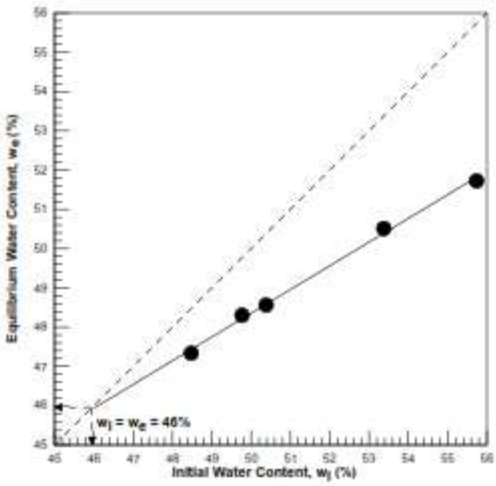

Fig 2 (c) - Liquid limit by k_o - Stress method for Kaolinitic soil (Soil No. 4).

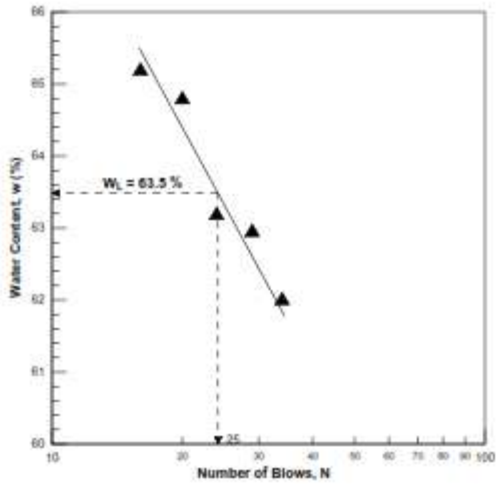

Fig 3 (a) - Liquid limit by Casagrande's method for Montmorillonitic soil (Soil No. 7).

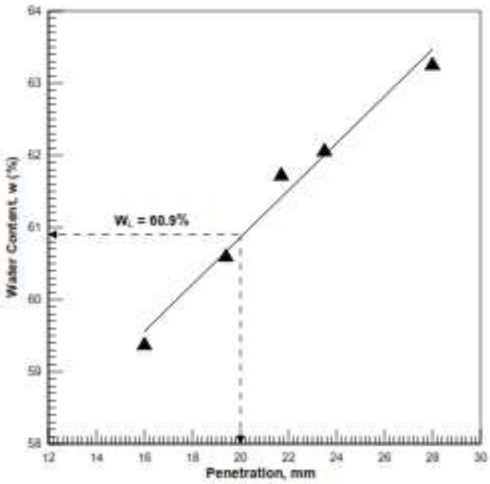

Fig 3 (b) - Liquid limit by Cone Penetration method for Montmorillonitic soil (Soil No. 7).

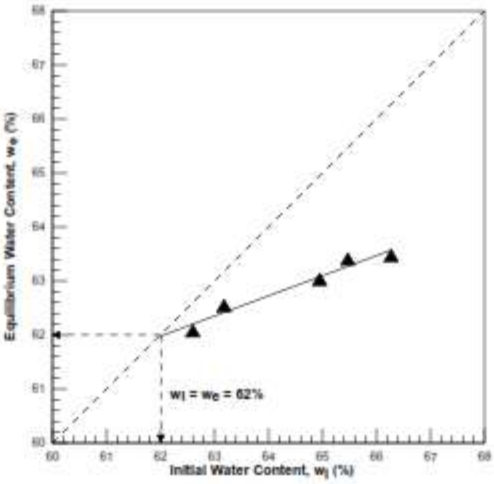

Fig 3 (c) - Liquid limit by k_o - Stress method for Montmorillonitic soil (Soil No. 7).

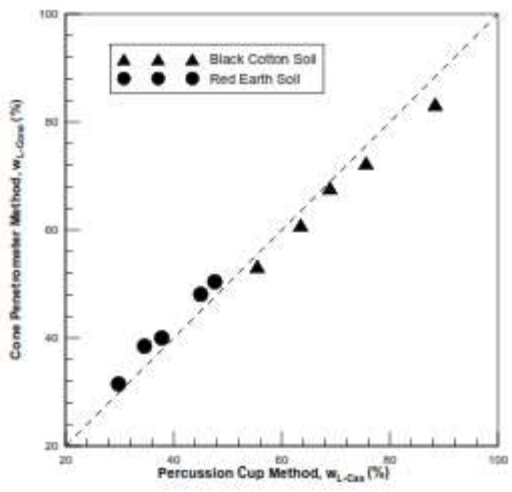

Fig. 4 - Comparative plot of liquid limit values obtained by cone penetration method versus Casagrande's Percussion cup method.

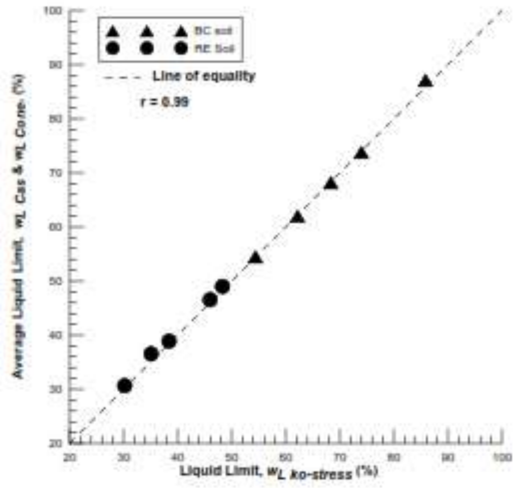

Fig 5 – Comparative plot of average values of liquid limit obtained by Casagrande and Cone method versus liquid limit obtained by k_o - stress method.

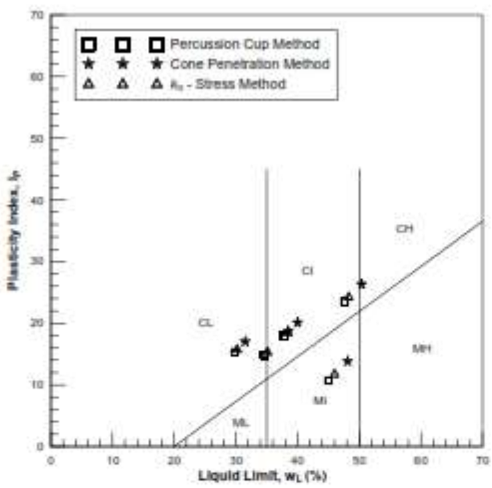

Fig 6 (a) – Position on the plasticity chart of the kaolinitic soils used in present study.

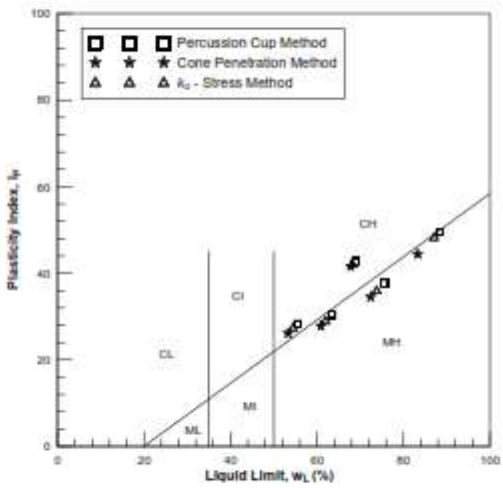

Fig 6 (b) – Position on the plasticity chart of the montmorillonitic soils used in present study.