



Note

Statistical variability of the correlation plasticity index versus liquid limit for smectite and kaolinite



Giovanni Spagnoli^{a,*}, Asuri Sridharan^{b,f,1}, Pierpaolo Oreste^c, Diego Bellato^d, Lucio Di Matteo^e

^a BASF Construction Solutions GmbH, Dr.-Albert-Frank-Straße 32, 83308 Trostberg, Germany

^b Indian National Science Academy, New Delhi, India

^c Department of Environmental, Land and Infrastructural Engineering, Politecnico di Torino, Corso Duca Degli Abruzzi 24, 10129 Torino, Italy

^d Department of International Projects and Services, BAUER Spezialtiefbau GmbH, BAUER-Str. 1, 86529 Schrobenhausen, Germany

^e Department of Physics and Geology, University of Perugia, Via Pascoli snc, 06123 Perugia, Italy

^f Indian Institute of Science, 560012 Bangalore, India

ARTICLE INFO

Keywords:

Atterberg limits

Smectite

Kaolinite

Probabilistic analysis

Confidence interval

ABSTRACT

An extensive literature review has been conducted to observe the statistical correlation of the plasticity index, PI, with the liquid limit, LL, of smectite and kaolinite. Fifty-nine data for smectite and fifty-one for kaolinite have been plotted and compared to each other. The results show that PI is related to LL with eqs. $PI = 0.97 \times LL - 37.6$ for smectite and $PI = 5.94e^{0.023 \cdot LL}$ for kaolinite. An independent data set was used for the validation of the proposed relationships. Besides, it was possible to identify a confidence interval for PI, relative to a certain interval for LL values, to confirm the robustness of the relations given above. The findings of this research show that the relation between the Atterberg limits is clearly controlled by the clay mineralogy and that there is no unique way to get PI from LL if the clay mineralogy is not considered.

Notation list

PI	Plasticity index (%)
LL	Liquid limit (%)
PL	Plastic limit (%)
R^2	Regression coefficient
k	Number of the available experimental points
m^*	Mean values of m (linear regression equation)
n^*	Mean value of n (linear regression equation)
$t_{\eta\%, n-2}$	Parameter t of Student, relative to a confidence level of $\eta\%$ and a degree of freedom of k-2
σ	Standard deviation

1. Introduction

Liquid (LL) and plastic limits (PL) are the basic geotechnical index parameters for the qualitative assessment of the physical properties of fine-grained soils. Atterberg (1911), who described first these parameters, stated that “the liquid limit represents the state at which two small pieces of clay placed in a bowl no longer flow together when a bowl is struck

violently and repeatedly on the hand” (Haigh, 2012), and it physically describes the water content at the transition from the liquid to the pulpy state of a soil. Soils at LL have small shear strength, which is in the range between 0.5 and 5.6 kPa (e.g. Wasti & Bezirci, 1986; Sridharan & Prakash, 1998). PL represents the water content at the transition from the rigid to the semi-solid state of a soil (DIN, 1997). Currently, there are two methods for obtaining LL: the Casagrande (1932) standardized cup method, which is a procedure currently defined in DIN 18122 part 1 (1997), AASHTO T89-07 (2007) and ASTM D4318-10 (2010), and the fall-cone-based method, standardized by the ISO/TS 17892-12 (2004) (Spagnoli, 2012). Regarding PL, the geotechnical standard procedure is given by the rolling test method.

Two different clay types have been investigated which represent the two extreme types of clay minerals: kaolinite (2-layered clay minerals) and smectite (3-layer clay minerals).

The latter has a 2:1 silica:alumina structure, with very weak van der Waals' forces (Sridharan, 2014), and repulsive forces between clay platelets which govern swelling (Taylor and Smith, 1986), mainly for Na-smectite (Olson and Mesri, 1970).

For kaolinite, positive cation exchange capacity was measured under low pH conditions when edges are positively charged indicates that some isomorphous substitution must exist (Mitchell and Soga,

* Corresponding author.

E-mail address: giovanni.spagnoli@basf.com (G. Spagnoli).

¹ He was formerly affiliated with Indian Institute of Science, 560012 Bangalore, India.

2005) which was also shown by Brady et al. (1996) and Israelachvili (2011).

As stated by Sridharan and Venkatappa Rao (1975), as these clays represent the extreme types of clay minerals, any natural clay is likely to behave, from the geotechnical point of view, in between these two. It is important to observe how the Atterberg limits will change depending on the clay mineralogy. Several authors tried already to assess the behavior of clays regarding their basic geotechnical properties (e.g.: White, 1949; Seed et al., 1964; Dusseault and Scafe, 1979; Nagaraj and Jayadeva, 1983; Sivapullaiah and Sridharan, 1985; Sridharan et al., 1988; Panadian & Nagaraj, 1990; Mitchell and Soga, 2005; Polidori, 2007; Dolinar & Škrabl, 2013), however no unique correlation was given. White (1949) found that LL of kaolinite increased with decreasing particle size, whilst Seed et al. (1964) obtained a linear correlation between LL and percentage of clay size for washed sand with kaolinite. Nagaraj & Jayadeva (1983) found a relationship, where the plasticity index, PI, was $0.74 \times (LL - 8)$, based on statistical approaches, critical state concepts and on the Gouy-Chapman theory of double layer. However, as stated by Sridharan (2014), since kaolinite and smectite behave quite differently from each other, the mechanisms governing the Atterberg limits, and in turn LL, of kaolinite and smectite are different. The present study summarizes the results of forty-four published data, where the Atterberg limits for almost pure clays were given. From the statistical point of view the confidence interval for confidence levels of 95 and 99% for both smectite and kaolinite has been assessed.

2. Methodology

Data from literature about LL and PL for smectite and kaolinite (or well-known natural clays with a predominant clay mineralogy) were carefully analyzed. Only Atterberg limits obtained with the Casagrande cup and the rolling method were used. Regarding smectitic clays, where possible, the main cation was indicated. However, according to Bain (1971), it is possible to roughly distinguish between Na-smectite and Ca-smectite considering their PI values. Clay fraction $< 2 \mu\text{m}$ were also indicated. Only Foreman and Daniel (1986), indicated the clay fraction corresponding to $5 \mu\text{m}$.

Forty-four different published data were used to obtain the Atterberg limits for pure clays, i.e. smectite and kaolinite mixed with water. Tables 1 and 2 summarize the values used for the interpretation of the Atterberg limits for natural clays mixed with water. LL values are obtained with the Casagrande cup. Fifty-nine data were used for the interpretation for the smectite, and fifty-one for the kaolinite.

3. Results and discussion

3.1. Correlations found

As LL value of clays depends on the type of clay mineral with associated cations (Mitchell and Soga, 2005), smectite and kaolinite have been analyzed separately. Fig. 1 shows the relation PI vs LL for smectitic clays. A linear correlation shows that $PI = 0.97 \times LL - 37.6$, with a very good correlation coefficient of $R^2 = 0.99$. The correlation PI vs LL for smectite is statistical significant as p-value is < 0.05 (i.e. 5.18×10^{-61}). The correlation matches very well with that found by Seed et al. (1964), where $PI = 0.98 \times LL - 27.5$, who investigated artificial kaolinite-quartz mixtures in different amounts. The correlation found by Nagaraj & Jayadeva (1983) was $PI = 0.74 \times LL - 8$; however, this was based on natural clays coming from different depths with inhomogeneous mineralogy. Regarding the kaolinite data, an exponential correlation between LL and PI was found (Fig. 2). The equation is in this case $PI = 5.94e^{0.023LL}$ and is characterized by a correlation coefficient of $R^2 = 0.80$. With respect to the data for the smectite, the results are more scattered. However, the correlation PI vs

LL for kaolinite is also statistical significant as p value < 0.05 (i.e. 1.74×10^{-19}).

wBearing in mind these findings, and considering the coefficient of correlations observed for smectite ($R^2 = 0.99$) and kaolinite ($R^2 = 0.80$), a comparison between experimental PI, which were derived from another published data shown in Table 3 and predicted PI values (obtained from the equations mentioned above) has been shown in Fig. 3A & 3B. As for Tables 1 and 2, for the values showed in Table 3 only data where Atterberg limit for the Casagrande cup on pure kaolinite and smectite were selected. Smectitic soils show a linear relation with a very good R^2 value (0.99), where $PI_{\text{predicted}} = 1.04 \times PI_{\text{experimental}}$.

For kaolinitic soils the predicted PI tends to overestimate the lab. PI up to 20%. From this point forward the predicted PI values underestimate the lab PI. The relation has the form of $PI_{\text{predicted}} = 0.48 \times PI_{\text{experimental}} + 10.26$.

This is likely due to the smaller R^2 values for the PI vs LL correlation with respect to the one obtained for smectite. However, the regression coefficient, R^2 , gives a value of 0.94. Besides, both p-values for Fig. 3A & 3B show also a statistical significance ($p < 0.05$) between the predicted vs lab PI values, with 3.60×10^{-10} and 3.46×10^{-06} for smectite and kaolinite respectively.

No significant correlation between LL and the percentage of clay size fraction was found for both smectite and kaolinite. This agrees with the findings of Sridharan et al. (1988), whereas disagrees with the statement of Seed et al. (1964) and Polidori (2007), who presented a linear variation of LL with the percentage of clay size fraction for quartz and pure clay mixtures. However, it is worth mentioning that the data of the literature reviewed used in this research refer to pure clays, which are normally characterized by a wider particle size distribution.

Fig. 4 (A and B) shows the relation PL vs LL as from Tables 1 and 2 for both pure clays. The purpose of the diagram is not to find out a relation; it is rather to show how the parameters change with respect to each other. Smectitic clays (Fig. 4A) show a bell-shaped behavior, where the highest PL value does not correspond to the highest LL value. The increases in PL values follow increases in LL values up to a certain point, after which LL values increases but PL values decreases. While LL values are directly proportional to the water content and to the main cation involved, PL values show considerable variations (Bain, 1971). According to Haigh et al. (2013), PL relates to the capillary suction at which the water phase ceases to act as a continuum.

It is interesting to note that some Ca-smectites have PL values higher than the Na-smectite samples. PL variations might be due to the difficulties of the thread-rolling tests and also because due to the different drying (shrinkage) characteristics of the smectitic clays (Bain, 1971), where the shrinkage is directly proportional to the PI (Taylor and Smith, 1986). Recent work shows the electrochemical forces play role in shrinkage processes (Lu and Dong, 2017). In that case, PL is also dependent on the electrochemical forces similar to the LL.

Regarding the correlation PL vs LL for kaolinitic clays (Fig. 4B), the trend is similar as observed in Fig. 2, i.e. an exponential function links in an acceptable way the two parameters ($R^2 = 0.70$). However, the correlations shown in Fig. 4 are not meant to be statistically relevant.

3.2. Estimation of the statistical variability of the PI vs LL correlation

In order to use the correlations obtained on the experimental measurements of Figs. 1 and 2 for smectite and kaolinite, an accurate probabilistic analysis is required. Since the collected data show some variability regarding the estimation of PI from LL, the estimation that can be made on PI leads to a probable range of variability rather than a simple deterministic value.

The confidence interval indicates the range that, with a certain probability (the confidence level), gives the true value of the parameter (Spagnoli et al. 2017).

Download English Version:

<https://daneshyari.com/en/article/8046121>

Download Persian Version:

<https://daneshyari.com/article/8046121>

[Daneshyari.com](https://daneshyari.com)