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Assessment of clay consistency through conventional methods and indirect extrusion tests

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ABSTRACT

The consistency of fine-grained soil is an essential parameter in soil mechanics. The most relevant consistency indices are the liquid limit and the plastic limit. The liquid limit is commonly determined through the Casagrande test or the fall cone test, while the plastic limit is determined through the hand rolling method. The greatest issue with some of these techniques is their low repeatability and operator dependency. In order to minimize those issues, an indirect-extrusion-based technique was evaluated as an alternative method to determine both consistency limits. The experimental work was carried out on mixtures of kaolin and bentonite to cover a wide range of plasticity. The results suggested that there is a specific extrusion pressure linked to each consistency limit and that the results are repeatable. The liquid limit obtained through the extrusion method closely matches the results of the fall cone test. Similarly, the plastic limit out of extrusion closely matches the results of the hand rolling method.

1. Introduction

In soil mechanics, consistency is a fundamental parameter for the classification of fine-grained soil. The most relevant consistency indices are the liquid limit (LL) and the plastic limit (PL). Conventionally, LL is determined through the Casagrande test or the fall cone test, while PL is determined through the hand rolling method. The greatest issue with some of these techniques is their low repeatability and operator dependency. In order to minimize those issues, an indirect-extrusion-based technique is evaluated as an alternative method to determine both, LL and PL.

Extrusion is the mechanical production process by which a block of a material (billet) is reduced in cross section by forcing it to flow through a die orifice (Shi-Bo and Jian-Xin, 2007; Muenstermann et al., 2009; Zhang et al., 2011). Extrusion can be direct or indirect as illustrated in Fig. 1. Under direct extrusion (Fig. 1a) the direction of sample flow and ram travel is the same. Initially, the extrusion pressure rises rapidly up to a peak value. Then as extrusion initiates, the pressure decreases as the wall friction component decreases. Finally, at the billet's end, the pressure increases once again as the billet becomes short and the material exhibits more resistance to exit through the die. Conversely, under indirect extrusion (Fig. 1b), the die moves against the sample. In this way, no frictional forces are mobilized.

The concept of extrusion was probably first applied for geotechnical purposes by Whyte (1982); however, his work was focused on establishing a relationship between undrained shear strength, extrusion pressure and water content. Kayabali and Tufenkci (2010) investigated the indirect extrusion to determine the consistency limits of different types of natural soil with plasticity index ($PI = LL - PL$) below 50, taking as reference the consistency limit tests described by ASTM D 4318 (2010). However, the reported correlation between consistency limits and extrusion pressure showed some spreading probably due to the impact of friction in their testing setup.

The aim of this paper is to investigate whether it is possible to establish a stronger correlation for the determination of consistency limits of clay through the indirect extrusion technique by minimizing all possible sources of spread. At the same time, the results are compared with test methods described in ASTM D 4318 (2010) and BS 1377-2 (1990).

2. Materials

Tests were carried out on artificial samples consisting of mixtures of different percentages of kaolin (K) and bentonite (B) to cover a wide range of plasticity (i.e., 100 K, 80 K + 20B, 60 K + 40B, 40 K + 60B, 20 K + 80B, 100B). Some properties of the clay used in this research are given in Table 1.

The clay specimens were mixed with different amounts of deionized water in a dough mixer for about 15 min. Then the wet samples were stored in airtight containers at about 20 °C for a period of over 1 day. ASTM D4318-10 suggests a minimum curing period of 16 h before testing.

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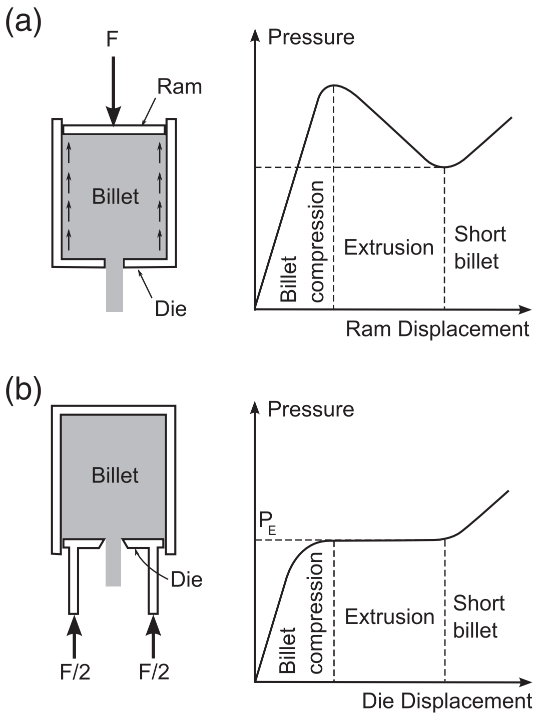

Fig. 1. Extrusion processes: (a) direct and (b) indirect.

The testing program on these samples included the execution of conventional tests to evaluate LL and PL and, more importantly, the development and evaluation of an indirect extrusion method. The outcome of the conventional tests serves as a reference for the calibration of the extrusion testing method.

3. Conventional testing methods

3.1. Evaluation of liquid limit

The liquid limit may be determined through the Casagrande cup test (ASTM D 4318, 2010) or the fall cone test (BS, 1377-2, 1990). The repeatability of the Casagrande cup method is known to be affected by operator judgment (Whyte, 1982; Özer, 2009). On the contrary, repeatability is not an issue for the fall cone test; however, the outcome of this test has to be carefully assessed as it will produce results for all soil types including non plastic soils, giving a wrong representation of plasticity (Prakash and Sridharan, 2006). The Casagrande cup and fall cone test do not produce the same results (Wasti, 1987; Schmitz et al., 2004; Prakash and Sridharan, 2006; Lee and Freeman, 2009; Özer, 2009; Zentar et al., 2009). In general, good agreement is observed for soils within an approximate range of 0% < LL < 70%. Outside this range, the fall cone test produces consistently lower LL values.

3.2. Evaluation of plastic limit

PL is evaluated out of the standardized hand rolling method (BS, 1377-2, 1990; ASTM D 4318, 2010). However, several fall cone-based methods are available in the literature (Wood and Wroth, 1978; Wasti, 1987; Feng, 2004; Lee and Freeman, 2009). In this research, the method proposed by Feng (2004) was followed as well. Here, four fall cone measurements are carried out to obtain cone penetrations ranging from 10 mm to 3 mm. Then PL is determined, through linear regression of the obtained data in a bi-logarithmic chart, as the water content corresponding to a cone penetration of 2 mm.

Table 1
Physical and chemical properties of the clay materials.

Index		Bentonite	Kaolin
Specific gravity	ASTM D 854	2.52	2.64
Liquid limit, %	ASTM D 4318	374.7	53.2
Plastic limit, %	ASTM D 4318	62.9	31.0
Swell index, ml/2 g	ASTM D 5890	18	3.5
CEC, mEq/100 g		73.77	1.38

4. Indirect extrusion testing setup

The equipment used for the indirect extrusion tests consists of a load frame provided with a platen that moves at adjustable constant rates, an indirect extrusion device (Fig. 2), a load cell with a capacity of 2 kN and a displacement transducer. The indirect extrusion device consists of a steel cylindrical container and a steel extrusion die. The die orifice with diameter d has a conical shape to minimize contact friction between the extruded sample and the die. The tube behind the die shows a length of about 110 mm to allow enough space for a soil thread to develop without interruptions. During a test, the die is set to travel against the clay sample at a constant rate v while the die displacement and the extrusion load are recorded.

The extrusion pressure (P_E) of a clay sample at a specific water content is evaluated out of the steady-state portion of the measured extrusion load vs. die displacement curve (e.g. Fig. 1b) through

$$P_E = \frac{F_E}{A} \tag{1}$$

where F_E is the steady-state extrusion load and A is the cross section of the sample container.

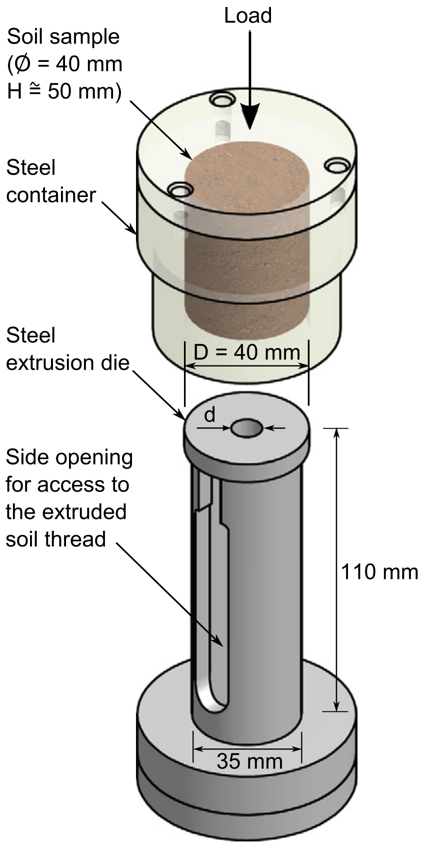

Fig. 2. Indirect extrusion device used in this research.