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Closure to Discussion by K. Prakash and A. Sridharan of "Atterberg Limits and Remolded Shear Strength – Water Content Relationships" [Geotechnical Testing Journal Vol. 36, No. 6, pp. 939–947]

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Abstract: This article presents the closure to the discussion on the Geotechnical Testing Journal, GTJ20130012, Vol. 36, No. 6, which had three stated objectives: (i) a critical assessment of empirical methods for predicting remolded undrained strength (s_{ur}) at different water contents on the basis of measured Atterberg limit values; (ii) a review of s_{ur} values mobilized at the Casagrande liquid limit (LL) and plastic limit (PL) conditions and hence the strength variation over the plastic range; and (iii) a new approach was propose for predicting s_{ur} values mobilized at different water contents. The original article stated the importance of clay mineralogy on clay behavior. A referenced comment was made regarding discourse by other researchers in recent literature on the link between mineralogy and differences in strengths at LL determined using the Casagrande cup and fall cone approaches. Although outside the immediate scope of the original article, this closure presents the opportunity to elaborate on this discourse since specifically raised by the discussers. The discussers also raised an unrelated but important point, namely attempts by several researchers of late to determine the PL using variants of the fall cone method. The author concurs with the discussers that these approaches deduce a strength-related reference water content that is fundamentally different from the lower water content limit for soil workability, which the Casagrande PL can be considered.

Keywords: Atterberg limits, clay, fall cone, mineralogy, shear strength

Closure:

The author would like to thank Professors Prakash and Sridharan for their interest in the paper and appreciate the contributions they have made to the understanding of the liquid limit and plastic limit tests. In essence, two main points are raised by the discussers: (i) the role of clay mineralogy; (ii) the use of mechanical approaches other than the Casagrande thread-rolling method for the determination of the *PL* of soils. Both points are addressed in turn by the author.

In relation to clay mineralogy, a considered reading of the paper shows the importance of clay mineralogical composition on fine-grained soil behaviour, with this point made in the Introduction and repeated on three separate instances later in the paper, along with associated references given to work by Wood (1990) and Trauner et al. (2005). The discussers have provided additional evidence and many more references to reinforce the importance of clay mineralogy on clay behaviour, which is welcomed. The discussers' cited the author's referenced comment that the link between mineralogy and differences in strengths at *LL* determined using the Casagrande cup and fall-cone approaches is still up for debate (see Experimental Results and Discussion section under subheading Strength at LL, $s_{\mathrm{ur}(LL)}$) for prompting them to write their discussion. The purpose of this comment by the author was to include the references in the paper to the latest thinking and literature on the subject at the time of writing the paper; namely the Closure by Haigh (2012b) to the Discussion by Prakash (2012) on "Mechanics of the Casagrande Liquid Limit Test" (Haigh, 2012a). In his Closure, while acknowledging that *'Differing soil mineralogies may well play a substantial role in the variation of strength with water content, and hence in the degree of deviation in water content between liquid limits measured using the two approaches'* (i.e., Casagrande cup and fall cone), Dr. Haigh went on to state that *'the available data (Sridharan and Prakash, 2000) appear to show the deviation between testing methodologies to be mostly a function of the liquid limit rather than having any great dependence on mineralogy.'* Further, on the discussers' view point that the undrained shear strength of fine-grained soil comprises two components, namely viscous shear resistance and frictional shear resistance, Haigh (2012b) stated: *'The "hypothesis" of different strengths mobilized using the two test procedures was used to explain a deviation between liquid limit values obtained by the two methods, which can now instead be explained based on the mechanics of the tests.'* The reader is referred to the Discussion (Prakash, 2012) and Closure (Haigh, 2012b) for further details. In this context, having presented deduced fall-cone and Casagrande-cup $s_{\mathrm{ur}(LL)}$ values for the 18 different soils considered in the paper under discussion, the author made his comment, with the above references. In relation to the *PL* state, more recently, in the Reply to a Discussion by Haigh and Vardanega on "Remoulded Shear Strength at Plastic and Semi-solid States", Professor Sridharan and co-workers stated that *'the mechanism controlling the plastic limit of fine-grained soils and the clay mineralogy effect are not clear'* (Vinod et al., 2013).

The second main point raised in the discussion concerned alternative mechanical approaches for the determination of the *PL*, in particular several researchers of late having advocated the use of variants of the fall cone method. As demonstrated in the paper and also in previous studies referred to by the discussers, neither the strength at the *LL* nor at the *PL* is unique and the ratio of strengths (R_{s}) between Casagrande *PL* and *LL* states is also not unique, but can vary over a large range. It is arguable that there is a need to develop more robust methods to determine the *PL* (Sherwood, 1970; Belviso et al., 1985; Wood, 1990) with, for instance, Vinod et al. (2013) stating that *"the 3 mm thread-rolling method may not yield accurately reproducible results"*. Nevertheless, the author agrees that any replacement 'plastic limit' deduced using a fall-cone approach is by definition simply a strength-related reference water content and not a measure of the lower water content limit for soil workability, as the Casagrande *PL* can be considered — so it is a new (alternative) index parameter. The author has written previously on this issue (see O'Kelly et al. (2011)). Hence, for instance, in the case where the *PL* value is based on an assumed R_s value of 100 (i.e., 100 times the strength mobilised at the fall cone *LL*), the proposed index parameter should be defined as PL_{100} (Stone and Phan, 1995), emphasising and recognising this fact. As pointed out above, this PL_{100} index is fundamentally different to the Casagrande *PL*, with any correspondence of actual values being pure coincidence. In other words, one should not expect the PL_{100} to align with the results from the Casagrande *PL* method as different mechanisms are at play in both tests (Stone and Phan, 1995; Haigh et al., 2013). It is also worth mentioning that in performing such fall-cone tests, a practical problem relates to the routine preparation of uniform test-specimens of the soil at water contents around the *PL*, which is difficult to achieve. Some of the other mechanical approaches advanced for *PL* determination may have merit. For instance, Barnes (2009) developed a novel apparatus that attempts to replicate the thread-rolling method for the determination of the *PL* of soils, allowing the detection of the brittle–plastic transition. By means of a loading device, stresses are applied during rolling, the thread diameter is measured for each rolling traverse, and plots of stress against strain are derived from which the workability or toughness of the soil is determined as the product of stress and strain. Perhaps it is timely for the geotechnical research community to investigate approaches along this or similar lines as potential alternatives for the determination of the Casagrande *PL* in practice. In conclusion, the author would like to thank the discussers for their contribution.

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