
Publisher's PDF, also known as Version of record

Link to published version (if available): 10.1680/geng.12.00093

Link to publication record in Explore Bristol Research

PDF-document

Permission is granted by ICE Publishing to print one copy for personal use. Any other use of these PDF files is subject to reprint fees.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available: http://www.bristol.ac.uk/pure/about/ebr-terms.html
Discussion: Remoulded shear strength at plastic and semi-solid states

P. Vinod PhD
College of Engineering Trivandrum, Thiruvananthapuram, India
A. Sridharan PhD
Indian Institute of Science, Bangalore, India
K. A. Deepa
Department of Civil Engineering, College of Engineering Trivandrum, Thiruvananthapuram, India

Contribution by S. Haigh and P. J. Vardanega
Vinod et al. (2012) have presented valuable data on strength variation with water content. There are, however, several points that we would like to make regarding the assessment of strengths at and beyond the Atterberg limits.

The authors attempted to measure soil strength both in the plastic range and in the brittle ‘semi-solid’ range using a vane shear apparatus. The vane shear test involves inserting a vane into a soil sample and measuring the resistance to rotation. The data are conventionally analysed by assuming that a constant shear stress is exerted over the entire surface area of the cylinder of rotating soil (ASTM, 2000). While this is appropriate for plastic materials in which strength will approach maximum strength at large strain, for brittle materials the variation in strain over the base of the cylinder will result in peak strengths not being achieved simultaneously. The maximum torque, when converted to a shear stress, will hence underestimate the peak strength of the soil. Further problems may also be created as the vane is inserted into the soil sample.

ASTM D 4648-00 (ASTM, 2000) asserts that: ‘The remoulded zone around a vane blade is generally assumed to be small and have little or no effect on the stress–strain properties of the sediment being tested.’ This assertion is again valid only for plastic materials; the process of inserting the vane must result in yielding of the soil. For a brittle material this will result in cracking of the soil sample, and hence an underestimate of peak strength during subsequent shearing of the soil.

As soils at water contents less than the plastic limit are by definition brittle, strengths measured using the vane shear apparatus at these water contents should be treated with caution. Strengths measured in triaxial compression, allowing constant strain to be accumulated within the sample and observation of the entire stress–strain relationship, would be a more appropriate approach.

The strength observed at plastic limit for the nine soils tested is approximately 161 kPa, very similar to that predicted by Wroth and Wood (1978). As shown by Haigh et al. (2012) and Nagaraj et al. (2012), plastic limit does not correspond to a fixed soil strength, merely to the onset of brittleness. Based on a data set of 71 strengths at plastic limit reported in the literature, Haigh et al. (2012) showed that the strength at plastic limit had a range of 17–530 kPa, with an average value of 152 kPa and a standard deviation of 89 kPa. While the data for nine soils presented by Vinod et al. (2012) fall centrally within this range, it would be wrong to assume that the small scatter of strengths found was representative of a wide range of soils.

The strengths observed at liquid limit were consistently found to be 5.8 kPa, much greater than the commonly reported range of 0.7–2.65 kPa (Wroth and Wood, 1978). It is unclear from the paper whether liquid limits were obtained using the fall-cone or Casagrande cup apparatus, which has a potential impact on the soil strength at the liquid limit. Using the fall-cone liquid limit, undrained strength might be expected to be approximately 1.7 kPa (Wroth and Wood, 1978), whereas at the Casagrande cup liquid limit the specific strength (strength divided by density) might be expected to be approximately 1 m$^2$/s$^2$ (Haigh, 2012), implying a range of strengths between 1.41 and 1.76 kPa for the range of soils presented. In either case 5.8 kPa appears excessive, calling into question the liquid limit values obtained. It is interesting to note that if the liquid limit were reinterpreted as being the point on the trendline at which the soil strength was 1.7 kPa, the regression relationship would become

$$c_u = 161.3 \exp^{-4.55 L}$$

almost identical to the expression given by Wroth and Wood (1978).

While the paper has offered strong evidence of the exponential relationship between strength and water content in the plastic region, more evidence would be required to use the expression derived with confidence for the prediction of soil strength. While we have also expressed concerns with regard to the methodology used to determine the variation of strength for soils at water...
contents below the plastic limit, similar trends shown are also
reflected in the data presented by Marinho and Oliviera (2012)
for compacted soils. With additional testing, this paper may prove
to have offered a valuable insight into the strengths of these
brittle materials.

Authors’ reply
The authors thank the discussers for their comments, and
appreciate the contributions they have made to the understanding
of the mechanics of liquid limit and plastic limit tests (Haigh,
2012; Haigh et al., 2012). However, the authors have certain
points on which they differ from the views of the discussers,
which are described below.

The discussers have commented at length on the applicability of
the vane shear test for determination of the undrained shear
strength of soils in the semi-solid state. Many of their statements
are valid. However, the prime objective of the authors was to
highlight the noticeable transition in the semi-solid state, in the
variation pattern of the undrained shear strength–water content
relationship of soils, from the well-known behaviour in the plastic
state. As a first attempt to investigate the relationship in the semi-
solid state, the authors felt that the laboratory vane test was an
adequate device for the role. The empiricism in the determination
of engineering behaviour of soils that has been discussed by
Burland (1987, 2006) is inevitable, and is useful in geotechnical
engineering situations such as that in the vane shear test, where
the peak shear strength is not mobilised simultaneously over the
entire soil surface. At the same time, the authors agree with the
discussers’ point that strengths measured in triaxial compression,
where the entire stress–strain relationship may be observed,
would be a more appropriate approach.

It is also recognised that the observed soil strengths at the plastic
limit reported in the literature (e.g. Haigh et al., 2012; Nagaraj et
al., 2012) show a wide scatter. The mechanism controlling the
plastic limit of fine-grained soils and the clay mineralogy effect are
not clear. The stress state during the thread-rolling plastic limit test
is known to be complex, owing to the lack of control on applied
stresses during the test (Whyte, 1982). At the same time, even
though it is agreed that the 3 mm thread-rolling method may not
yield accurately reproducible results, the method still measures the
soil plastic limit controlled by cohesion, which cannot be measured
by the fall-cone test, wherein the controlling mechanism is
undrained friction (Prakash and Sridharan, 2006). Prakash et al.
(2009) have shown that reproducible and reliable results can be
obtained even with the 3 mm thread-rolling method, if the test is
conducted by an experienced person. It is accepted that the
difference between the liquid limit and the plastic limit, which
represents the range of plasticity of a fine-grained soil, is due to the
mouldability of the soil, and therefore is controlled by the soil
cohesion. The plasticity properties are invariably to be measured by
those tests where the factors controlling plasticity come into play.

As far as the determination of liquid limit is concerned, it has
been hypothesised that the liquid limit obtained from the percus-
sion method is controlled primarily by viscous shear resistance
due to the diffuse, double-layer-held water, and the cone method
is essentially governed by undrained frictional shear resistance at
the particle level. Detailed discussion on the mechanisms control-
lng the above two methods of determination of liquid limit are
reported elsewhere (Sridharan and Prakash, 1998; Sridharan et
al., 1986, 1988). There is a good match between the mechanism
controlling the liquid limit of montmorillonite soils (i.e. thickness
of the diffuse double layer) and the dominant mechanism in the
percussion method (i.e. viscous shear resistance due to diffuse
double-layer water). Similarly, there is good agreement between
the mechanism controlling 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
(i.e. frictional resistance at the particle level). In view of the
above, the authors used the percussion method for the liquid limit
determination of bentonite, Cochin marine clay and Kuttanad clay,
whereas the cone method was used for Chittoor clay, Malappuram
clay, Palakkad clay, Thonnackal clay, lateritic soil and kaolinite.

The observed values of shear strengths at the liquid limit in the
study are higher than most of the reported values. This may be
due to the sensitivity in the determination of shear strength at
water contents close to the liquid limit, irrespective of the method
adopted.

Although the discussers have welcomed the strong evidence of
the exponential relationship between shear strength and water
content, they have expressed concerns over its practical applic-
ability. As in any other research work, more evidence would be
required to use the expressions derived with confidence for the
prediction of soil strength, particularly for soil in the semi-solid
state. Further refinements can be made by using a large body of
data of shear strengths.

REFERENCES
miniature vane shear test for saturated fine-grained clayey
soil. ASTM International, West Conshohocken, PA, USA.
view. Proceedings of the 9th European Conference on Soil
Mechanics and Foundation Engineering, Dublin, Ireland,
vol. 3, pp. 1427–1447.
Burland JB (2006) Interaction between structural and
technical engineers. The Structural Engineer 84(8):
29–37.
Haigh SK, Vardanega PJ and Bolton MD (2012) The plastic limit
11.P123.
Marinho F and Oliviera OM (2012) Unconfined shear strength of
compacted unsaturated plastic soils. Proceedings of the
Institution of Civil Engineers – Geotechnical Engineering


