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DISCUSSION

Using the BS cone penetrometer for the determination of the plastic limit of soils

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The Author has proposed a new method for the determination of the plastic limit of soils using a single cone penetrometer. It was Schofield & Wroth (1968) who suggested that the index limits be expressed in terms of strength and made a proposal for the redefinition of the plastic limit as the water content at which the soil's strength is one hundred times its strength at the liquid limits, idealizing the results of Skempton & Northey (1953). Extending this work, Wroth & Wood (1978) defined detailed procedures for the measurement of the plastic limit using the fall cone test with two geometrically similar cone penetrometers.

The Author's method has a number of features in common with that of Wroth & Wood (1978) namely,

(*a*) use of the fact that soils at their respective liquid limit and plastic limit correspond approximately to fixed strengths which is in the rough ratio of 1 : 100

$$c_{PL}/c_{LL} = 100 \qquad (1)$$

(*b*) Use of the dimensionless cone factor.

$$c_u d^2/W = k(\alpha, \chi) \qquad (2)$$

where W is the cone weight and d is the depth of penetration of the cone; α the apex angle; and χ is a measure of the friction between the soil and the cone (Houlsby, 1982).

The new characteristics of the method proposed by the Author appear to be as follows (as in Fig. 3)

(*a*) a bilinear idealization of the liquidity index I_L against the logarithm of cone penetration (or strength) relation

(*b*) the intersection of the two straight line segments at a point with d about 14 mm and use of extrapolation at $d = 2$ mm.

These along with equations (1) and (2) are used by the Author in his proposed method for the direct determination of the plastic limit using a single cone.

In the method of Wroth & Wood (1978), they derived the following expression for the redefined plasticity index $(I_P)_r$ from which the cone penetrometer based plastic limit w_{PC} can be calculated

$$(I_P)_r = \Delta \ln 100/\ln(W_2/W_1) \qquad (3)$$

where Δ is the vertical separation in terms of water content w on the linear plots of w against the logarithm of the cone penetration d for two geometrically similar cones of weight W_1 and W_2 ($W_2 > W_1$). Hence the use of a linear idealization of the liquidity index I_L against the logarithm of cone penetration (or strength) relation.

$$w_{PC} = w_{LC} - (I_P)_e \qquad (4)$$

where w_{LC} is the cone penetrometer based liquid limit and other symbols have been defined earlier.

I have tested residual soils of predominantly kaolinitic origin (Wijeyakulasuriya & Muraleetharan, 1986). It is thought that these data would provide additional insight into the determination of plastic limit using the cone penetrometer. Fig. 6 shows that for these soils, in the range of cone penetrations observed, a linear idealization is well supported. However, as the water content decreases in the vicinity of low cone penetrations, plots of water content against the logarithm of shear strength may be curved, showing a more rapid increase of log c_u with decrease in water content (Wood, 1985). Hence the linear extrapolation of results from $d = 5$ mm to $d = 2$ mm by the Author may not seem to hold valid for all soils. Although lacking experimental support for the extrapolation, it does seem to make close predictions for the Bandung Clays.

I have adopted the two cone method proposed by Wroth & Wood (1978) to determine the plastic limit, Fig. 7. The cone penetrometer plastic limits are always much lower than the results from the conventional thread rolling tests. Index properties determined using the cone penetrometer need not be expected to correspond precisely with index properties determined using other devices and procedures. However, it may be desirable to define test conditions with the cone penetrometer in order to achieve a closer correspondence with index properties determined using conventional

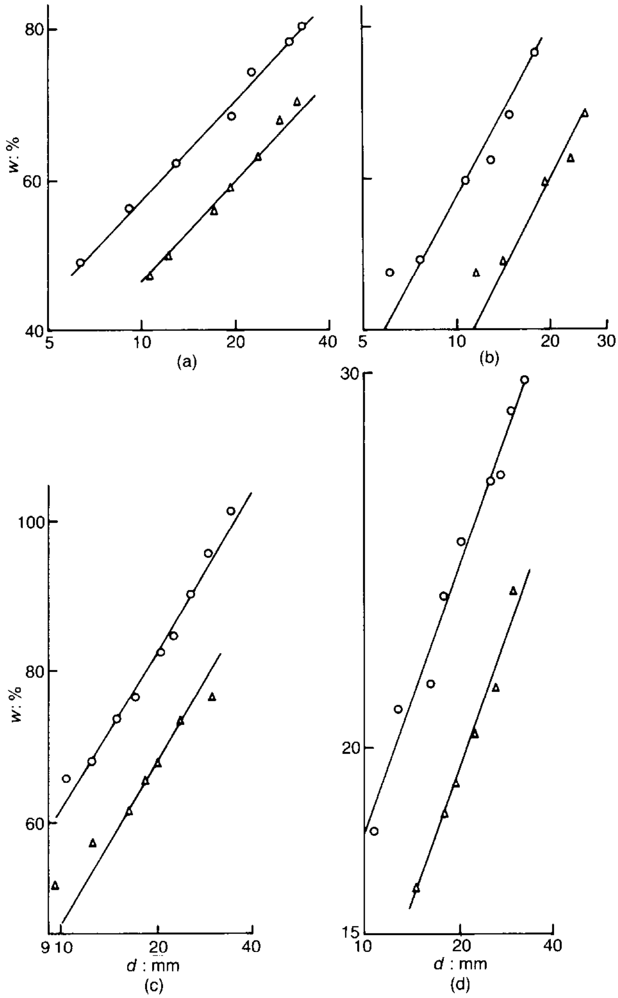

Fig. 6. Variation in penetration *d* with water content *w* for cones of weight 80 gf and 230 gf with apex angle 60°: (a) Kotmale; (*b*) Kelanitissa; (c) Kaolin; (d) Kopay

devices and procedures, as this would enable a ready extension of existing correlations of index properties with basic geotechnical engineering parameters.

The proposed redefinition of the plastic limit as a definition in its own right may suffer due to the prediction of very low plastic limits making the experimental verification of the strength ratio assumed (100) difficult at such low water contents. At worst, if the adopted strength ratio were to predict negative values for the plastic limit (Wijeyakulasuriya & Muraleetharan, 1986; Wasti & Bezirci, 1986) i.e. $(I_P)_r > w_{LC}$, then a re-examination of the strength ratio adopted is desirable. Let the strength ratio corresponding to the water content change between the cone penetrometer based liquid limit w_{LC} and the thread rolling plastic limit w_P be R. For my test data, I found that the Casagrande liquid limits and the cone based liquid limits were bounded between the $\pm 10\%$ lines from the 45° line, falling within the same variability as observed by Sherwood & Ryley (1970). Now equation (3) can be written as

$$(I_P)_{rR} = \Delta \ln R / \ln (W_2/W_1) \quad (5)$$

where $(I_P)_{rR} = w_{LC} - w_P$. This leads to the following expression for R

$$R = \exp\ [(I_P)_{rR} \Delta \ln (W_2/W_1)/\ \ ] \quad (6)$$

The value of R backfigured varied between 7 and 28 with an average of 18 from nine samples. This

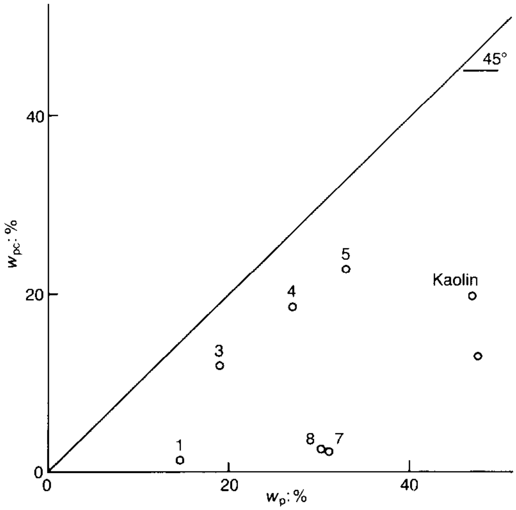

Fig. 7. Relation between thread rolling plastic limit and cone penetrometer based plastic limit

is close to the value of 25 obtained by Lawrence (1980) from direct measurements with speswhite kaolin.

Equation (5) $(I_P)_{rR}$ is sensitive to both the linearity idealization and to the strength ratio R assumed. Wasti & Bezirci (1986) attributed the inapplicability of the cone method for the determination of the plastic limits of their bentonitic soils to the invalidity of the assumption of linearity of the water content–cone penetration relationship. This appears to be justified for the highly compressible bentonite soils. For the moderately compressible kaolinitic soils, I believe a suitably reduced value of R based on direct measurement should be adopted in order to make the cone penetrometer based plastic limit to be close to the conventional plastic limit.

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Author's reply

The Author agrees with Mr Wijeyakulasuriya that at low cone penetrations the values of $\log C_u$ increase more rapidly with decrease in water content. Fig. 8 shows the relation between water content, in terms of liquidity index I_L, and logarithm of undrained shear strength $\log C_u$. Realizing the curvature relationship between these two parameters, a bilinear model is adopted instead of a linear model.

The Author's proposed method for plastic limit determination using a single cone is basically the same as the determination of relationship between $\log C_u$ and water content using the same mean. However, the fall-cone test has a limitation in that it can only give acceptable result of pen-

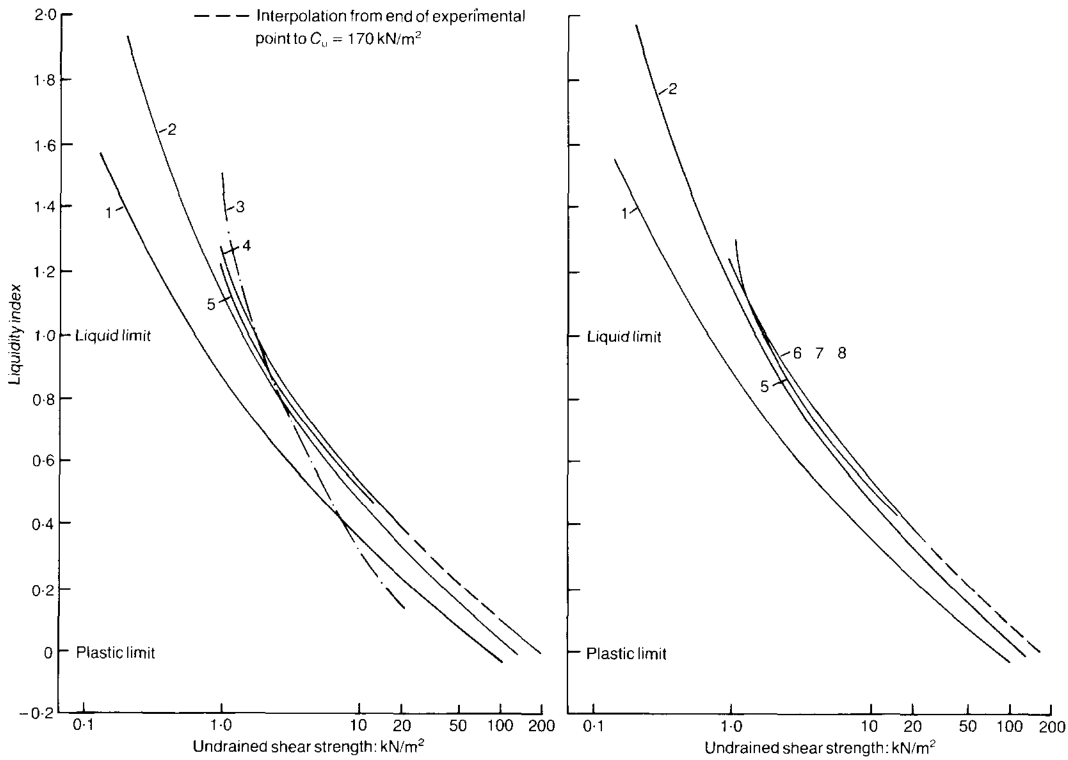
Table 3. Equations obtained

Clay	I_L equal to
Horten (Skempton & Northey, 1953) Cambridge Gault Clay	$1{\cdot}08–0{\cdot}70(\log C_u) + 0{\cdot}09(\log C_u)^2$
Combined data of Cambridge Gault Clay (Wood, 1985) and four Bandung Clays	$1{\cdot}18–0{\cdot}77(\log C_u) + 0{\cdot}11(\log C_u)^2$

Table 4. Predictions of plastic limit and undrained shear strength at $I_L = 0$ by bilinear relationship

Clay	Predicted values			
	W_P	C_u at $I_L = 0$	W_P	C_u at $I_L = 0$
Horten	15	100	16	120
Shellhaven	30	70	32	80
Cambridge Gault	27	150	28	170*
Speswhite kaolin	23	30	35	170*
Bandung	†	120	†	170*

* Assumed that C_u at $I_L = 0$ is 100 times that at $I_L = 1$.
† See technical note concerned.



Clay	Test method	W_l/W_p
1. Shellhaven (Skempton & Northey, 1953)	—	97/32
2. Horten (Skempton & Northey, 1953)	—	30/16
3. Speswhite kaolin (Wood, 1985)	Vane shear	61/35
4. Cambridge Gault Clay (Wood, 1985)	Vane shear	69/28
5. Bandung (z^* = −7·0)	Fall-cone	61/39
6. Bandung (z = −7·0)	Fall-cone	64/36
7. Bandung (z = −2·0)	Fall-cone	30/36
8. Bandung (z = −5·0)	Fall-cone	66/41

*z = depth of sample from ground surface: m.

Curves 4, 5 and 6, 7, 8 can be represented by a polynomial model:

$I_L = 1{\cdot}182 - 0{\cdot}768\,(\log.\,C_u) + 0{\cdot}107\,(\log.\,C_u)^2$

Fig. 8. Relationship between liquidity index and undrained shear strength

etration measurement as low as 5 mm. Lower than this, the results are unreliable. Curves 5, 6, 7 and 8 in Fig. 8 shows the relation between I_L and $\log C_u$ using the fall-cone test. The values of C_u were determined by equation (3) of the Author technical note. While the cone factor k is taken equal to 0·85 as proposed by Wood (1985) for 30° of cone angle. The broken part of the curve is the extrapolation from the lowest penetration measurement to a point in which $C_u \simeq 170\,\mathrm{kN/m^2}$ at $I_L = 1$ (Wroth & Wood, 1978).

The relation between I_L and $\log C_u$, as shown in Fig. 8, are well represented by a second degree polynomial model—i.e. $I_L = a + b \log C_u + c(\log C_u)^2$. Using the method of least squares, the following equations were obtained, shown in Table

3. For a second degree polynomial, the values of b and c indicate the pattern of the curve—i.e. the tangent at any point in curve. Since b and c values of both Horten Clay and combined data are almost the same, it thus can be concluded that the both curves have the same pattern. Fig. 8 also shows that except for speswhite kaolin, all curves have the same pattern for I_L less than 0·75.

The bilinear relationship as proposed by the Author is used only for plastic limit determination, not for C_u at low water content. Table 4 shows the results of plastic limit and C_u at $I_L = 0$ determination for soils mentioned in Fig. 8 using a bilinear model. Except for speswhite kaolin, a bilinear model gives close predictions the plastic limit of all soils, whereas for C_u at $I_L = 0$ the results are too low and thus the use of a second degree polynomial is suggested (refer to the details described earlier in this discussion). This method can also be used for extrapolating from cone penetration of 5–2 mm, if the bilinear model gives an unsatisfactory result as in speswhite koalin. Perhaps the simple way is to establish the relation between water content and log C_u (or log penetration of fall-cone test) for some local soils like curves 6, 7 and 8 in Fig. 8 for Bandung Residual soils. Then extrapolation can be made following the pattern of the established curve.

REFERENCES

Hansbo, S. (1957). A new approach to the determination of the shear strength of clay by the fall-cone test. *Proc. R. Swed. Geotech. Inst.*, No. 14.

Houlsby, G. T. (1982). Theoretical analysis of the fall cone test. *Géotechnique* 32, No. 2, 111–118.

Lawrence, D. M. (1980). *Some properties associated with kaolinite soils*. MPhil thesis, Cambridge University.

Schofield, A. N. & Wroth, C. P. (1968). *Critical state soil mechanics*. London: McGraw-Hill.

Sherwood, P. T. & Ryley, M. D. (1970). An investigation of a cone penetrometer method for the determination of the liquid limit. *Géotechnique* **20,** No. 2, 203–208.

Skempton, A. W. & Northey, R. D. (1953). The sensitivity of clays. *Géotechnique* **3,** No. 1, 30–53.

Wasti, Y. & Bezirci, M. H. (1986). Determination of the consistency limits of soils by the fall cone test. *Can. Geotech J.* **23,** 241–146.

Wijeyakulasuriya, C. V. & Muraleetharan, K. K. (1986). The cone penetrometer and the index limits of some Sri Lankan soils. *Proc. Asian Regional Symp. on Geotech. Problems and Practices in Foundn. Engng, Colombo* **1,** 314–319.

Wood, D. M. (1985). Some fall cone tests. *Géotechnique* **35,** No. 1, 64–68.

Wroth, C. P. & Wood, D. M. (1978). The correlation of index properties with some basic engineering properties of soils. *Can. Geotech. J.* **15,** No. 2, 137–145.