EVALUATION OF POSSIBLE SWELLING POTENTIAL OF SOIL

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ABSTRACT

A study of the Atterberg Limits of different clays has shown that the ratio of Liquid limit to Plastic limit defines the type of clay present in a soil. This ratio R (or plasticity ratio) is shown to be related exponentially to Skempton's Activity. The clay fraction within a given soil can now be estimated without any hydrometer analysis. van der Merwe's zones of swell potential have been mathematically defined and a chart giving the swell potential of a soil from the value of R and P_{425} fraction is presented.

1. THE VALUE OF THE ATTERBERG LIMITS

What is not often appreciated is the value of the Plasticity Index and the Liquid and Plastic Limits as a means of estimating the type of clay present in a soil. In 1951 a table published by Cornell University gave inter alia the following data as shown in table 1 below:

Table 1: Atterberg Limits of Clay Minerals

Clay Mineral	Exchangeable ions	Liquid Limit	Plastic Limit	Plasticity Index	Shrinkage Limit
Montmorillonite	Na	710	54	650	9.9
	K	660	98	562	9.3
	Ca	510	81	429	10.5
	Mg	410	60	350	14.7
	Fe	290	75	215	10.3
Illite	Na	120	53	67	15.4
	K	120	60	60	17.5
	Ca	100	45	55	16.8
	Mg	95	46	55	14.7
	Fe	110	49	49	15.3
Kaolinite	Na	53	32	21	26.8
	K	49	29	20	-
	Ca	38	27	11	24.5
	Mg	54	31	23	28.7
	Fe	59	37	22	29.2

A study of these figures led the writer to conclude that the ratios: LL/PI and PI/PL were quite significant: See table 2 below:

Table 2: Values of LL/PI and PI/PL for clay minerals

Clay Mineral	Ions:	Na	K	Ca	Mg	Fe	Average	SAY
Mont-morillonite	LL/PI	1.09	1.17	1.19	1.17	1.34	1.19	:
	PI/PL	12	5.73	5.30	5.90	2.86	4.96	
	LL/PL	13,1	6,10	6,30	6,90	3,83	5,9	6.0*
Illite	LL/PI	1.79	2.00	1.82	1.73	2.24	1.91	
	PI/PL	1.26	1.00	1.22	1.20	1.00	1.15	
	LL/PL	2.26	2.00	2,22	2,08	2,24	2,16	2,25*
Kaolinite	LL/PI	2.52	2.45	3.45	2.35	2.63	2.68	
	PI/PL	0.65	0.68	0.40	0.74	0.59	0.61	
	LL/PL	1,64	1,67	1,38	1,74	1,55	1,59	1,50*

The ratio LL/PL only is selected

As the ratio LL/PI is the product of LL/PI and PI/PL the ratio LL/PL may be accepted as a clay type indicator. LL/PL = R and may be termed the PLASTICITY RATIO.

As can be observed, there is a distinct difference between the ratio LL/PL and the type of clay mineral and we can thus get a fair indication of the type of clay present in the soil as the PI is related to the LL and PL.

As montmorillonite is a very high swelling clay and kaolinite very low we can get a fair idea of what shrinkage or swelling we can expect, in our soil if we calculate R (=LL/PL) from tests results.

2. THE VALUE OF ACTIVITY AND THE CLAY FRACTION

Skempton in 1953 related the plasticity index and the clay fraction in clayey soils, which he termed Activity as follows for three clay types:

$$\text{Activity} = PI/P_{002} \qquad (1)$$

Sodium Montmorillonite:	7.2
Illite	0.9
Kaolinite	0.38

These values of 0.38; 0.9 and 7,2 for Activity relate exponentially well with the R values for these clays namely:

$$\text{Act} = 0{,}16R^{2{,}13} \qquad (2)$$

(See Figure 1)

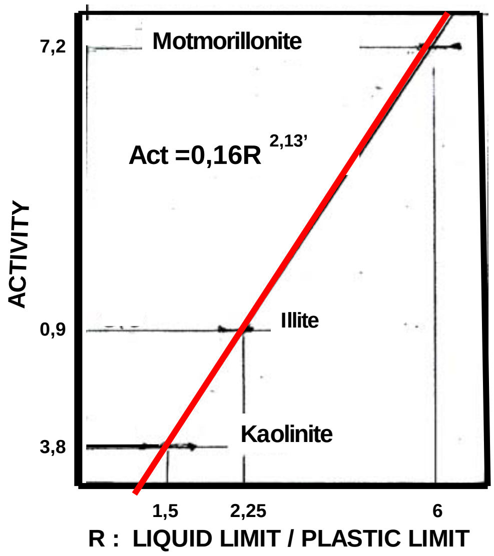

Figure 1: Graph showing the relationship between Plasticity Ratio (R) and Gross Clay Fraction (P002)

Skempton's (1953) definition of activity (equation 1 above) and equation 2 enables us to estimate the clay content (P_{002}) of a soil if the value of R is known.

Thus:

$$P_{002} = PI/Act = PI/0{,}16R^{2.13} = 6.25PI.R^{-2.13} \quad (3)$$

The value P_{002} here relates to the clay fraction for that portion of the soil that was tested for PI which is generally on the P_{425} fraction. Thus for a true estimate of the P_{002} content for the full soil equation (3) becomes:

$$P_{002} = 6.25PI.P_{425}.R^{-2.13} = 6.25Pg.R^{-2.13} \quad (4)$$

Where PI x P_{425} is the gross PI for the total soil (Pg). Equation 4 enables us to estimate the clay fraction for a soil without performing a tedious laboratory hydrometer analysis. See Figure 2 for graphically solving equation 4.

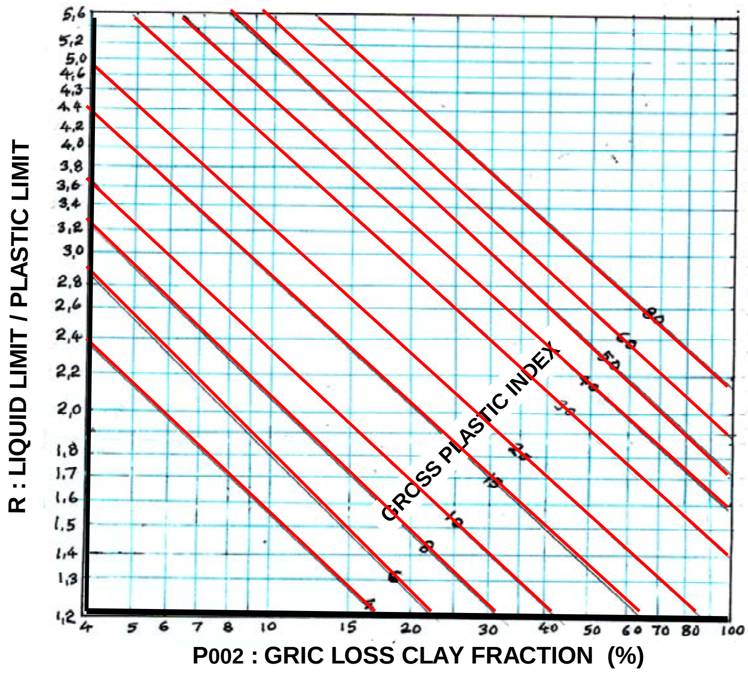

Figure 2: Estimation of Clay Fraction from Plasticity Ratio and Plasticity Index

3. THE SWELL POTENTIAL OF SOIL

Van der Merwe (1964) investigated the potential of clays to swell and drew up a chart of Gross PI (Pg) versus gross clay fraction (P_{002}g) in which zones of swell potential were defined ranging from low – medium – high –very high by a series of straight lines (See Figure 3).

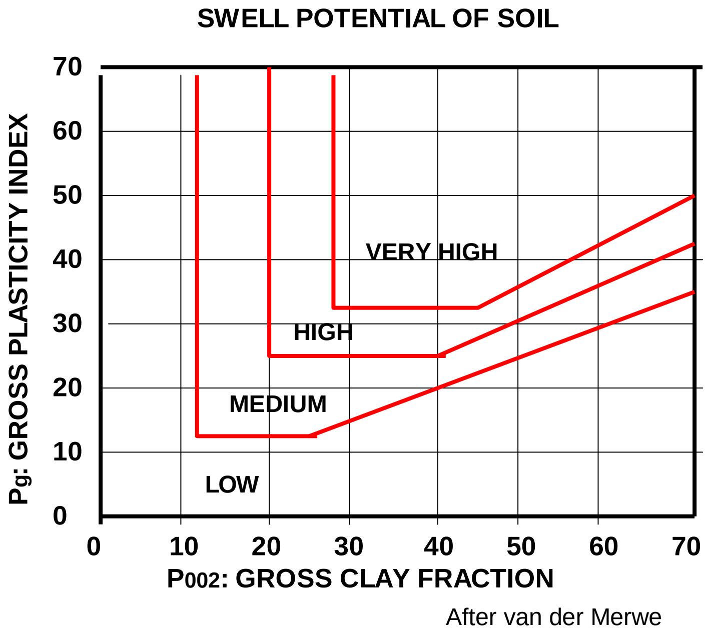

Figure 3: van der Merwe's zones of swell potential of soil.

The writer has established a mathematical derivation of lines representing swell potential by a factor K, certain values of which define the swell zones approximating those of van der Merwe (1964). The mathematical evaluation of K which relates gross PI (Pg) and gross clay content ($P_{002}g$) is given by:

$$(P_{002} - 0{,}73K)(Pg - 0{,}16P_{002}\,K^{0{,}4}) - K = 0 \qquad (5)$$

Swell potential is defined by K, when:

$K \leq 16$	low swell potential
$16 < K \leq 27$	medium swell potential
$27 < K \leq 37$	high swell potential
$37 < K$	very high swell potential

Figure 4 shows the K lines superimposed on the original van der Merwe zones. It will be noticed that a high degree of coincidence is apparent. The writer considers this should be quite acceptable.

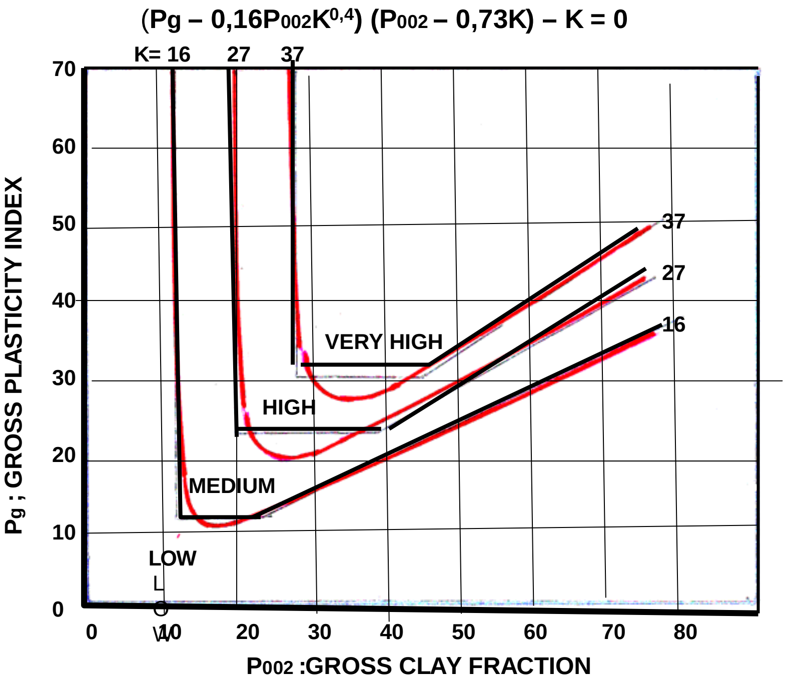

Figure 4 The van der Merwe zoning in terms of mathematical formulation

As will be observed equation 6 and Figure 4 incorporate the clay fraction $P_{002,}$ tests for which are generally not performed when indicator tests are done but equation 5 can be re-formulated to eliminate P_{002} by substitution from equation 4 where: $P_{002} = 6{,}25PgR^{-2{,}13}$

Thus:

$$Pg(1 - K^{0{,}4} x\, R^{-2{,}13})(6{,}25PgR^{-2{,}13} - 0{,}73K) - K = 0 \qquad (6)$$

As this formula is rather extended for rapid calculation Figure 5 has been prepared which enables the swell potential of a soil to be estimated when the value of the PI and the LL/PL (= R) is known. An additional value for K (=57) has been added in order to divide very high swell potential and extremely high potential.

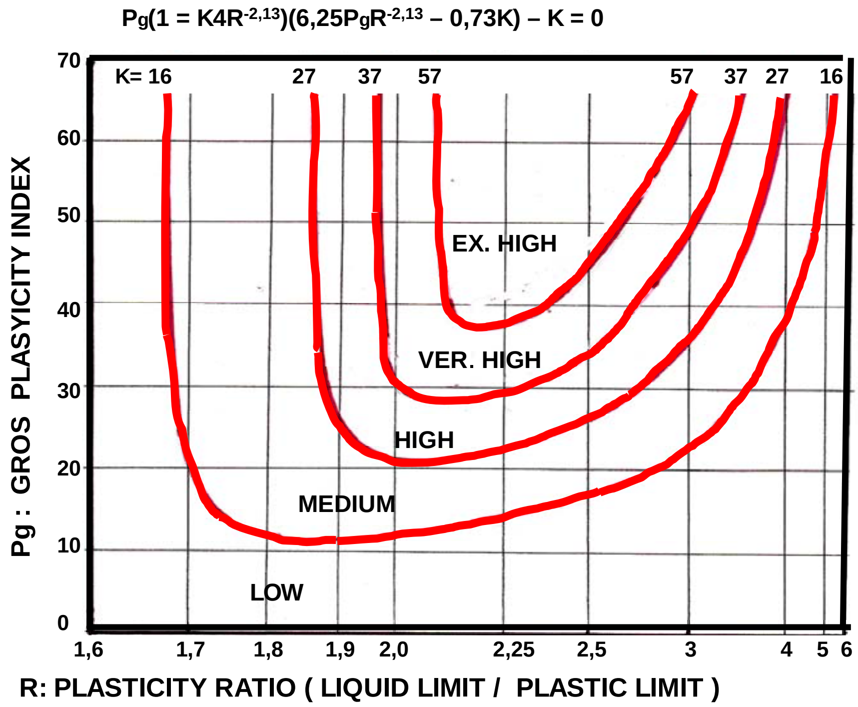

Figure 5 Swelling potential of soil by use of the Atterberg Limits of Plasticity Index and Plasticity Ratio

4. EXPANSIVE SOILS

When an expansive soil is compacted it will not retain its density as an increase in moisture content will cause it to swell and thus lose density. This is undesirable in any road structure. It is thus not advisable to compact an expansive sub-grade or to use such a soil in a road fill. The writer recommends that soils that have a K value of 27 or more should be treated as unsuitable for compaction as a sub-grade or for use in a fill.

The use of the R value (LL/PL) for a soil and the PI gross will enable a suspect soil to be assessed quickly by the use of the chart given in Figure 5. It should be noted that LOW and MEDIUM swelling soils may be accepted for compaction but soils approaching the HIGH zone should be considered suspect. Clay soils which fall within the high swell range or higher should not be compacted as any high density if achievable will not be retained, should an increase in moisture occur.

5. CONCLUSION

Experience has made the writer doubtful of the accuracies of the hydrometer analysis for clay fraction determination for several reasons.

- Stokes' law assumes all particles to be spherical and clays are flaky.
- De-flocculation of many clays is seldom fully completed at the time of testing.
- Clay particles are partially carried down by the larger particles
- A relative density of 2,65 is assumed for all particles, which may not be true.

It is thus surely reasonable to rely more on the accuracy of the Atterberg limits and clay activity in determining a reasonably accurate clay fraction value and swell potential.

This relatively simple system of the use of the Atterberg Limits and P_{425} only for swell assessment will enable the Roads Engineer to decide rapidly whether a given soil should or should not be compacted or should or should not be used in a fill.

6. REFERENCES

[1] Cornell University, 1951. Final Report on Soil Solidification Research. Ithaca, New York.

[2] Skempton AW, 1953. The Colloidal Activity of Clays. 3rd International Conference Soil Mech found Eng. Switzerland, vol. 1.

[3] Van der Merwe DH, 1964. The prediction of Heave from the Plasticity Index and the Clay Fraction. Civil Engineering, South Africa vol. 6 no. 6.