INSIGHTS INTO PAVEMENT MATERIAL DENSITY AND STRENGTH

P F SAVAGE

Prof Emeritus: University of Pretoria; Specialist Consultant, suite 359, Private Bag x4,
Menlo Park, Pretoria, 0102

ABSTRACT

Properties of soils provide far more information than typically used in construction quality control. The aim of this paper is to present mathematical evidence of the relation between soil properties such as porosity, soil interlock and bearing capacity and to demonstrate it's applicability in pavement layer construction control. Basic soil parameters are presented, and their interrelationships, whereafter these parameters are combined in mathematical relationships and their application in quality control demonstrated.

The determination and use of the soil parameters; porosity and degree of interlock is suggested as a more pragmatic means of assessment of a state of soil compaction than the more traditional Relative Compaction of a so called maximum laboratory density. Soil groups may be related to porosity at maximum density which can be mathematically calculated from a single “one-shot” density test. Strength in the form of a possible minimum CBR of a soil at different moisture contents and density is shown to be mathematically assessable.

1. INTRODUCTION

A study of the behaviour of soils during the process of compaction both in the field and in the laboratory has caused the writer to become increasingly aware that Road Engineers are not making as full a use of many soil parameters as they should. Densities in the field are compared with densities obtained in the laboratory to which a shear strength in the form of a CBR may be attached. Surely this is a very round about and time consuming method of assessing a field strength of a compacted soil layer when a simple determination of porosity (n) or it's cousin the degree of interlock (I) will give a direct and immediate indication of strength.

The soil groups G4 to G10 can and should be coupled directly with porosity of the soil at say Modified Density for the soils. A better understanding of applied effort and a soil’s frictional resistance to particle interlock also merits a further study here.

The aim of this paper is to present possible mathematical evidence of the relation between soil properties such as porosity, soil interlock and bearing capacity and to demonstrate it's applicability in pavement layer construction control. Basic soil parameters are presented, and their interrelationships, whereafter these parameters are combined in mathematical relationships and their application in quality control demonstrated.

Proceedings of the 25th Southern African Transport Conference (SATC 2006) 10 – 13 July 2006
ISBN Number: 1-920-01706-2 Pretoria, South Africa
Produced by: Document Transformation Technologies cc Conference organised by: Conference Planners

2. SOIL PARAMETERS

As mathematical formulations are to be used in the analyses put forward in this study it is necessary to define certain soil properties and the symbols attached thereto:

2.1 Relative Density (G)

The relative density of a soil particle is the ratio of the particle's mass to the mass of the same volume of water. As soil particles may contain an unknown volume of air bubbles within their own volume the so-called solid relative density (G_{so}) is hypothetical and is not to be used in density assessments.

Particles also exhibit cracks or fissures within their surface. These cracks contain air but are part of the particles whole. If the volume of these cracks or fissures is not assessed the relative density of the particles is known as apparent relative density (G_{ap}).

The true relative density of the soil particles takes the volume of the cracks or fissures as part of the particle's value and is known as bulk relative density (G_{bk}).

If the volume of any particle's solid part is Vs, the air bubbles Va and the non-penetrable fissures Vf the three degrees of relative density may be defined as follows where the mass of the equivalent volume of water is taken as unity and that of the particle as M.

$$G_{so} = \frac{M}{V_s}$$

$$G_{ap} = \frac{M}{V_s + V_a} \tag{1}$$

$$G_{bk} = \frac{M}{V_s + V_a + V_f}$$

2.2 Water Absorption (q)

When determining the bulk relative density of soil the volume of the fissures must be measured and this is done by testing for the mass of water absorbed into the fissures after 24 hours of soaking. On surface drying the soil particles, weighing, oven-drying and reweighing, the mass of absorbed water can be measured. The ratio of this mass to that of the oven-dry particles, is termed the water absorption and carries the symbol q. These tests are executed according to Methods B14 and B15 of TMH1:1986. Thus:

$$q = \frac{Mass\ of\ absorbed\ water\ in\ cracks}{Mass\ of\ oven\ dried\ particles} \tag{1a}$$

From this it can be proven that

$$G_{bk} = \frac{G_{ap}}{1+q} \tag{1b}$$

2.3 Soil Density (D)

Soil Density (D) is defined as the total mass of the particles (including water if present) divided by the total volume of the particles as well as the inter-particle voids. If water is present the density is defined as wet density. (It should be noted that adsorbed or ionic water which may be attached to particle surfaces is not included as moisture content here as this water is not driven off by normal oven-drying and is considered as part of the particles' mass).

Thus, if the water content (W) is expressed as a fraction of the particles' mass, wet and dry densities are defined as follows: (Where M is the dry mass of the soil and V_g the gross volume of the soil):

$$D_{dr} = \frac{M}{V_g} \qquad \text{(kg/m}^3 \text{ or t/m}^3\text{)}$$

$$D_{wt} = \frac{M}{V_g}(1+W) \qquad \text{(kg/m}^3 \text{ or t/m}^3\text{)} \qquad (2)$$

A high density value for D is generally accepted as an indication of a high strength but unless compared with a density of known strength it is meaningless on it's own. When density is coupled with relative density of a soil of known strength a direct measure of strength may be indicated.

2.4 Porosity (n) and Degree of Interlock (I)

Particles of soil are not blocks of equal size that may be packed closely together with no open spaces. They are irregular and however well compacted will always result in an open space between the particles known as inter-particle voids. Porosity is defined as the ratio of the volume of inter-particle voids in a soil mass to that of the total volume of the mass. If V_t is the total mass of the compacted soil and V_v that of the voids, porosity n is defined as:

$$n = \frac{V_v}{V_t} \qquad (3)$$

If n represents the volume of voids within a given volume of compacted soil then I, the degree of particle interlock may be defined as the total volume of the solids or the degree of togetherness of the particles. Thus:

$$I = 1-n \qquad (4)$$

Note: The term "interlock" defined here conveniently describes particles togetherness and may not necessarily agree with general geotechnical terminology.

The ratio of density to relative density is a direct measure of I.

$$\frac{D}{G_{bk}} = I \qquad (5)$$

from which:

$$n = 1 - \frac{D}{G_{bk}} \qquad (6)$$

The parameters n and I are direct indicators of a soil's strength as they both relate to the particle interlock or togetherness of a soil. A soil with a high I or low n can be directly assessed as having a high strength. Consider two soils A and B each compacted to a density of 2100 kg/m^3 but for A, G_{bk} = 3.0 and for B, G_{bk} = 2.5. Table 1 clearly indicates that D on it's own is no criterion for strength.

Table 1. Parameters I and n as a measure of strength.

Soil	A	B
D	2.1 t/m^3	2.1 t/m^3
G_{bk}	3.0	2.5
I = D/G_{bk}	70%	84%
n = I – D/G_{bk}	30%	16%
Strength potential	Low	High

The use of porosity is clearly far more advantageous for defining soil strength than that of density. Do engineers use this important parameter? The determination of G_{bk} for a soil is not even included as part of the so-called indicator tests! The writer recommends that relative density G_{bk} be a prerequisite test for all soils to be used in earthworks compaction and should form an integral part of all indicator tests in future.

2.5 Degree of Saturation (S)

The quantity of water within a soil mass can readily be expressed by the proportion of the voids that are filled with water. This fraction is termed the degree of saturation (S). This parameter for the measurement of water content, unlike moisture content, is quite independent of the soil particles' relative density as it represents the volume of water relative to the volume of voids in a total volume of voids and solids.

Assume that the two soils A and B above each occupy 1m^3 of volume and let each have a moisture content of 6.1%. Table 2 illustrates how vastly different the water in each soil type can be:

Table 2. Illustrating the significance of the degree of saturation.

Soil Type	A	B
Mass of dry soil (kg)	2 100	2 100
Moisture Content (%)	6.1	6.1
Mass of water: (kg) (2100x0,061)	128	128
Volume of water (V_w)(m^3)	0.128	0.128
Porosity (n) (%)	30	16
Volume of voids (V_v)(m^3)	0.30	0.16
Degree of Saturation $S = \frac{V_W}{V_V}$ (%)	43%	80%

The degree of saturation (S) here clearly indicates that soil A is still relatively dry while soil B is very close to saturation (and is in fact virtually at OMC). If soil A has to also be given a degree of saturation of 80% it's moisture content would have to be increased to 11.4% (the OMC for soil A).

It is worth drawing attention at this stage to the fact that the OMC for compacted soils occurs when the degree of saturation is 80% for all practical purposes. This is the condition when virtual saturation is taking place and further additions of water start pushing particles apart or destroying interlock and a fall off in density occurs. Not all soils may show an OMC at S = 80% but at this level of density differences from the assumed 80% for S may be considered as negligible.

2.6 TRH14 Soil Groups (G_g)(G4-G10)

When a good quality G4 soil is compacted, a porosity of 15% at modified density could be achieved but a G9 soil compacted under modified effort will probably only give a porosity of not less than 30%. Each soil group can include a “best quality” as well as a “worst quality” soil with it's scope. For the purpose of this paper, the TRH14 classification is amplified. A value for G_g which includes a decimal, would clearly indicate within the group the region into any one soil fits. For example a G5.2 soil would be within the better portion of the Group 5 while a G5.9 soil would still fall within the definition of a G5 but would in fact be close to a G6 in quality.

2.7 Soil Strength

When a soil is compacted the degree of densification achieved is dictated by the soil’s resistance to further particle interlock. This resistance is related to the moisture content or lubrication to overcome friction between the particles. As more of this friction is overcome by further application of water the same applied effort will consequently produce a higher densification or lower porosity for moisture contents below the OMC. This state of particle interlock (1-n) is a direct indication of the soil’s resistance to further densification and is related to the effort applied. If the same effort is applied for different moisture contents or degrees of lubrication the soil strength is also the same for each state of densification and it's corresponding moisture content. It is thus evident that a line or contour joining all points of density vs moisture content is also a contour line of equal soil strength. If a plot were to be made of the insitu CBR (i.e. the CBR at the density compacted by a given effort) and the moulding moisture content along the dry leg of a moisture density curve the values theoretically would all be the same.

3. MATHEMATICAL RELATIONSHIPS

Having defined the above soil properties it is necessary to understand the relationships which they bear to each other and apart from those already listed in equations 1 to 6 above the following additional formulations will contribute to a proper understanding of the behaviour of soil:

3.1 Some Factual Relationships

Density and Relative Density ($G = G_{bk}$) are related to water content by:

$$W = S\left(\frac{1}{D} - \frac{1}{G}\right) \qquad \text{(D in tonnes/m}^3\text{)} \qquad (7)$$

Multiplying both sides by D gives:

$$WD = S\left(1 - \frac{D}{G}\right) = Sn \qquad (8)$$

When D_m is the modified density of a soil and W_o the OMC, S here may be taken as 80% so the porosity at Modified Density is:

$$n_m = 1.25 W_o D_m \qquad (9)$$

This is useful if G_{bk} is not known. In fact equation 9 enables estimation of an effective relative density (G_{ef}).

$$G_{ef} = \frac{D_m}{1-n_m} \qquad (10)$$

3.2 Some Derivations

The writer's experience and his studies on the behaviour of compacting soils has lead him to make the following assumptions which in the absence of any strong cases to the contrary may from an engineering point of view be accepted as reasonable: (These are assumptions based on general observations. The writer is unfortunately acutely aware that research is needed here).

a. Soil Groups (G_g) can be related linearly to porosity at Mod. Density.
b. Based on the specified minimum requirements for the compaction of soil groups in COLTO with respect to CBR (soaked) and Relative Compaction a mathematical relationship between soil porosity and minimum CBR (soaked) can be established.
c. The peaking point of the moisture density curve occurs when the degree of saturation is 80%.
d. The wet leg of the moisture density curve falls along the S = 90% line for the most part.
e. The dry leg of the moisture density curve for estimating Modified density is the mirror image of the wet leg where the wet leg is that for S = 90% as it approaches their intersection.
f. For any given compactive effort applied in determining the dry leg of the moisture density curve the density achieved for any moulding moisture content establishes the soil's strength. The dry leg is thus a strength contour for the soil and reflects the resistance presented by the soil for further densification above that obtainable by the effort applied at the moulding moisture present.

From assumption (a) above and the lower limits of porosity for G4 and G9 soils suggested above the following relationship is derived.

$$G_g = \frac{n_m}{0.3} - 1 \qquad (11)$$

Following on the assumptions considered in point b minimum CBR values laid down in COLTO for soil groups can be related to the corresponding porosity at the relative compaction specified. The CBR and n when plotted logarithmically gave an excellent correlation as follows: (See Figure 1).

$$n_{RC} = 0.6C^{-0.28} \qquad (12)$$

Where n_{RC} = porosity at the Rel Comp for the soil group.

C = minimum probable soaked CBR

Equation I2 enables the road engineer to specify a minimum porosity in the field to ensure that a certain minimum soaked CBR will be achieved. Specifying a minimum relative compaction to that of a laboratory standard density would appear now to be unnecessary.

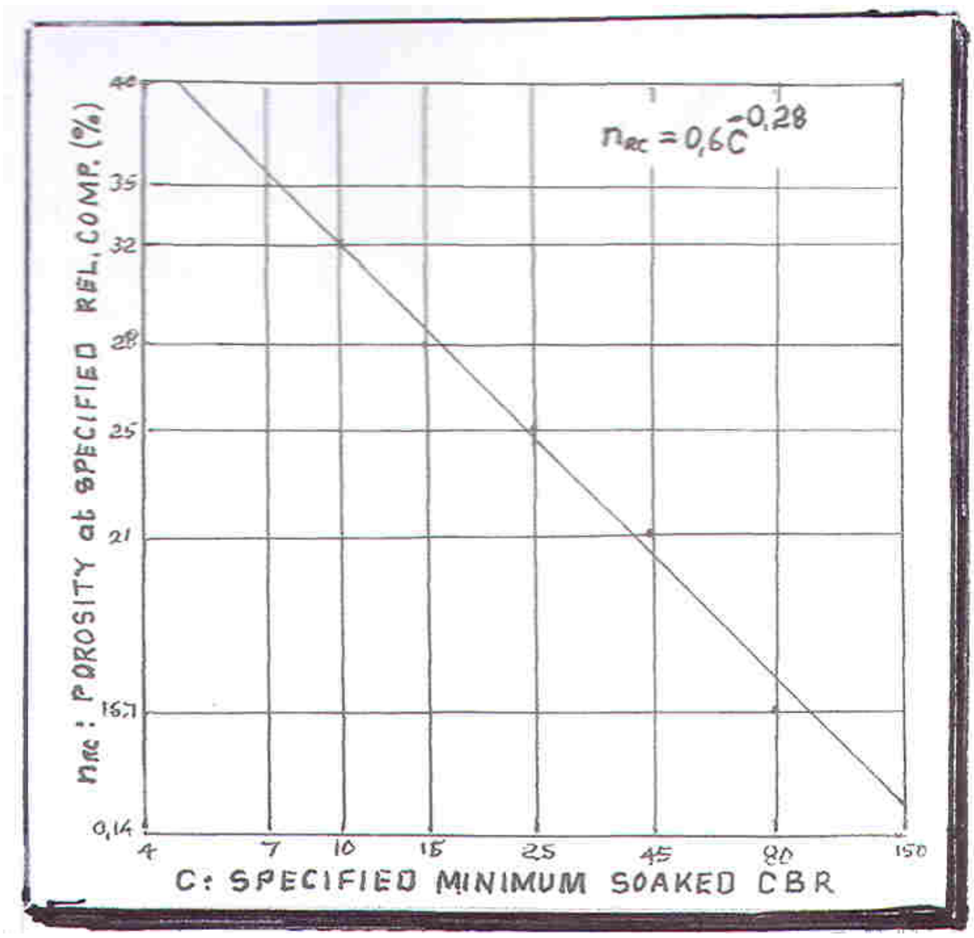

Figure 1. Log plot of porosity vs CBR.

Assumptions c, d and e above lead the writer to formulate mathematical equations for the dry and wet legs of a moisture density curve for the S = 90% and 80% conditions: (See Figure 2):

$$W_{d9} = 0.90\left(\frac{1}{G_{ef}} - \frac{1}{D_d}\right) + 2W_o \qquad (13)$$

and $$W_{d8} = 0.80\left(\frac{1}{G_{ef}} - \frac{1}{D_d}\right) + 2W_o \qquad (14)$$

where:

- W_{d9} and W_{d8} = The moisture content coordinate on the dry leg for S = 90% and 80% respectively.
- D_d = The density achieved by a given effort corresponding to the moisture W_{d9} and W_{d8}.
- W_o = The moisture content at the intersection of the dry and wet legs and represents the OMC for the compactive effort applied.
- G_{ef} = G_{bk} in this case.

If D_o is the density (hypothetical) for the intersection of the dry and wet legs for S = 90%, applying formulae (13) and (7) we get:

$$\frac{1}{D_o} = 0.5\left(\frac{1}{D_d} + \frac{1}{G_{bk}} + \frac{W_d}{0.9}\right) \qquad (15)$$

and for density D_m the maximum density for the applied effort at the crown of the moisture density curve (See Figure 2):

$$\frac{1}{D_m} = \frac{0.56}{D_d} + \frac{0.44}{G_{bk}} + 0.63W_d \qquad (16)$$

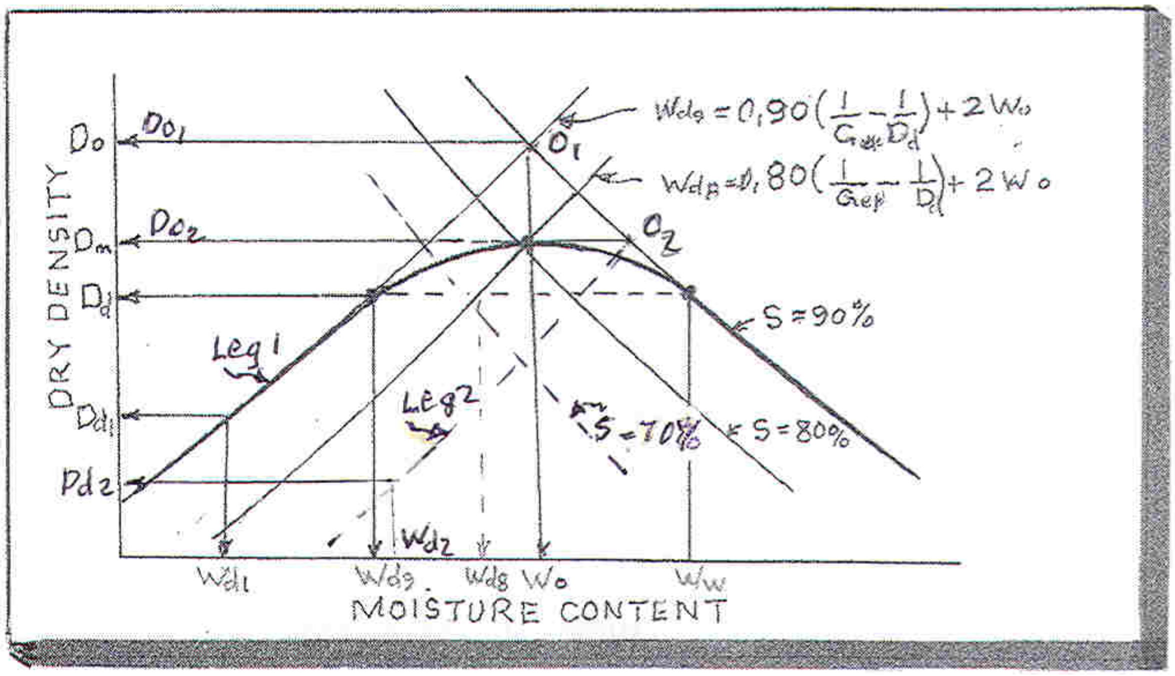

Figure 2. Mathematical formulations of dry and wet legs.

(The mathematical derivations of the formulae (15) and (16) have been omitted here for the sake of brevity).

Equation (16) enables one to calculate the modified (or Proctor) maximum density when a single "one-shot" densification on the dry leg (D_d and W_d) has been performed preferably at not too low a moisture content. (Compare this with the time consuming and tedious method of repeating 5 to 6 moisture density tests to draw the moisture density curve!) It may be accepted that the dry leg may deviate from the wet leg mirror image at low moisture contents.

Based on the assumption f above, the following conditions presented themselves.

On a moisture density graph a density $D = D_m$ would represent a Modified or maximum density for a point D_d, W_d on a dry leg. If the D_m has a porosity n_m this would exhibit a soaked CBR where D_m intersects the S = 90% wet leg. See Figure 2 which shows this point as O_2. This same point would be the D_{O2}, or the intersection point of a lower order dry leg (leg 2) which would thus have the same numerical CBR value but it would be the unsoaked CBR for this leg.

This is to say that n_m (where $n_m = 1 - D_m/G_{bk}$) and n_{o2} would be equal (where $n_{O2} = 1 – D_{o2}/G_{bk}$).

If equation 15 is multiplied by G_{bk} we get:

$$\frac{G_{bk}}{D_{o2}} = 0.5\left(\frac{G_{bk}}{D_d} + \frac{W_d G}{0.9} + 1\right) = \frac{G_{bk}}{D_m} \text{ (from above)} \qquad (17)$$

Now from equation 10.

$$\frac{G_{bk}}{D_m} = \frac{1}{1 - n_m} \qquad (18)$$

However, n_m here is the porosity at maximum density (e.g. Modified defined effort) but equation 12 gives the value of CBR for densities at relative compaction.

A plot of n_{RC} vs n_m is shown in figure 3 from which the relationship:

$$n_m = 0.87\, n_{RC}^{1.0114} \qquad (19)$$

or simply, with negligible error

$$n_m = 0.87\, n_{RC} \qquad (20)$$

from the equations 20 and 12 we get:

$$n_m = 0.52 C^{-0.28} \qquad (21)$$

and from equations 18 and 17

$$\frac{1}{1 - 0.52 C^{-0.28}} = 0.5\left(\frac{G_{bk}}{D_d} + \frac{W_d\, G_{bk}}{0.9} + 1\right) \qquad (22)$$

or $$C = \left\{1.92\left(1 - \frac{2}{\frac{G_{bk}}{D_d} + W_d \frac{G_{bk}}{0.9} + 1}\right)\right\}^{-3.57} \qquad (23)$$

The chart shown in Figure 4 represents graphically the minimum CBR value that can now be associated with various conditions of D and W or better, the idealized parameters $I = \frac{G_{bk}}{D}$ *and* $W.G_{bk}$. Equation 23 enables the CBR scale to be plotted along the S = 90% wet leg. The dry leg lines are the mirror image of the S = 90% wet leg and may be termed the 90% dry legs.

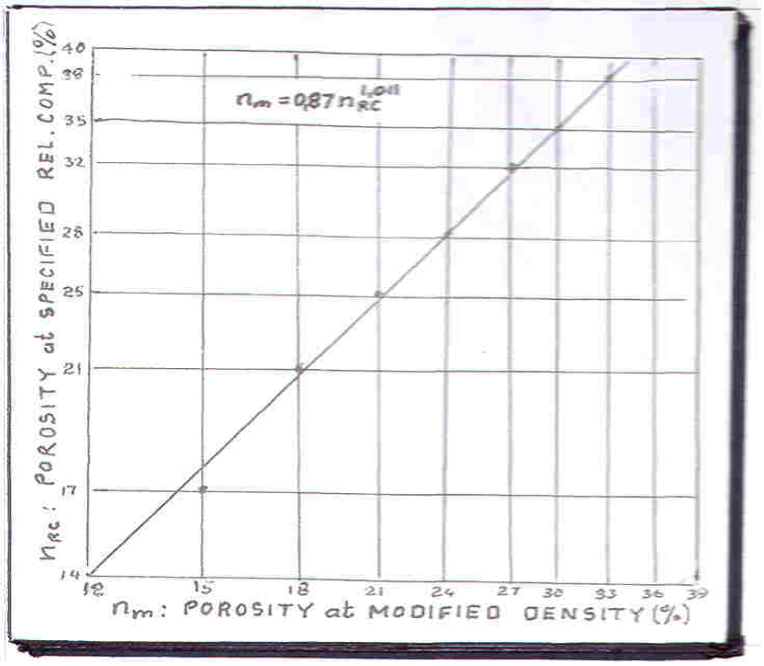

Figure 3. Log plot of n_{RC} vs $n_{m.}$

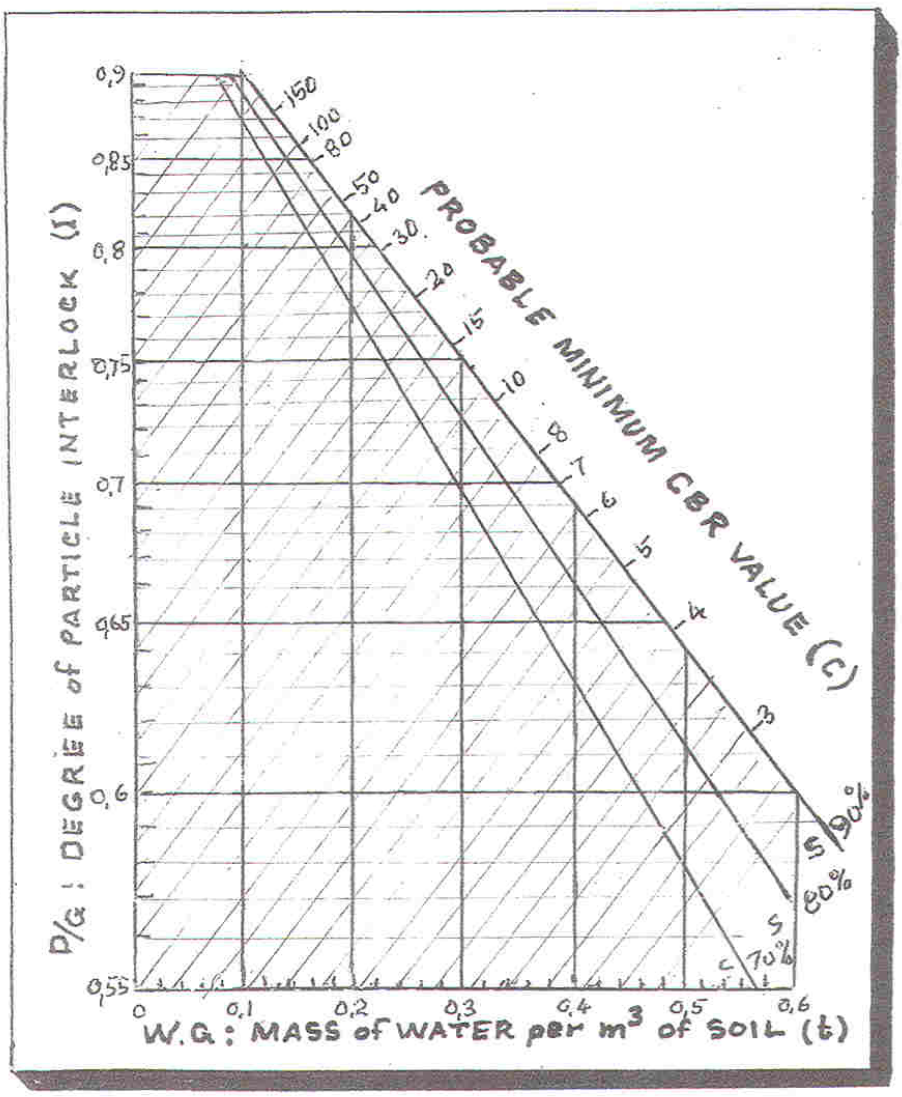

Figure 4. Chart for estimating probable minimum CBR.

4. APPLICATIONS

This study into the relationships of soil properties during compaction has led the writer to consider strongly whether the time is now perhaps right to have a "new think" about our present handling of density or compaction control of soil layers. A few suggestions follow, which it is hoped, may encourage road engineers to give serious thought towards a revision of our current practices in the field of compaction control.

4.1 Suggestion No. 1

Density on it's own is not a satisfactory parameter for assessing a soil's strength. If however, the relative density of the soil particles is applied to density a completely different picture is presented. The expression $\frac{D}{G}$ clearly indicates the degree of particle interlock (I) which is a vital term in a modified Coulomb definition of soil strength

$$S = FI + \sigma \tan \varphi \qquad (24)$$

Where F is a conversion factor to bring FI into line with stress. (S here must not be confused with degree of saturation. It is of course dependant on moisture content).

It is strongly suggested that the testing for relative density of the soil particles be included as part of the indicator tests such as Atterberg Limits and Grading analysis.

4.2 Suggestion No. 2

When a compacted layer of soil is tested for density, this density is related to a standard density established for that soil to which a strength has been attached by means of so-called CBR tests. If the field density meets the required Relative Compaction the strength of the layer is thus assured. The standard density test or Moisture density test is time consuming and needs some 50 kg of material. The CBR tests are even more time consuming and need more material. What a round about way of satisfying our assessment of a compacted layer!

If the degree of particle Interlock (I) or it's cousin (n) (where n = 1-I) are known surely a measure for n in the field layer will give us directly the very strength parameter needed. Surely specifying a maximum value to be achieved for n can save endless toil and trouble. This specifying of a minimum n value is presently applied in the compaction of crushed rock layers (G1) where n must not exceed 12%.

It is strongly suggested that the degree of compaction of a soil layer should be specified, by requiring a minimum porosity or a maximum $\frac{D}{G}$ value in place of relative compaction. Note that this form of densification control obviates any taking of samples at the point of test except that required for a moisture content determination.

4.3 Suggestion No. 3

If a moisture density test on any soil shows a porosity (n_m) at maximum density this can be coupled directly to the soil group as given in equation 11.

By relating a soil group (G_g) with a porosity at Modified density, this density or porosity immediately identifies the group. Based on a G4.0 yielding a porosity of 15% and a G9.0 a porosity of 30% all at 100% modified density and assuming a linear relationship for the remaining groups, equation 11 was formulated.

Equation 11 relates porosity to the soil group and with past experience which specifies a relative compaction to that of modified it appears reasonable to place limits of porosity n which could be achieved for each group. Table 3 gives limiting porosity requirements as suggested by the writer.

Table 3. Suggested maximum values for n_m and n_f for Soil Groups.

Soil Group	G4	G5	G6	G7	G8	G9
n_m at mod dens (%)	15-18	18-21	21-24	24-27	27-30	30-33
n_f for field (%)	17-22	22-25	25-28	28-32	32-35	35-39

The lower values for n_f would apply to the lower values of n_m while the higher values apply to the higher values of n_m within any soil group.

Although the writer is perfectly amenable to placing soils within a Soil Group (G_g) he is of the opinion that more emphasis should be placed on the value of n_m at maximum density and the corresponding degree of interlock achievable.

4.4 Suggestion No. 4

When a normal moisture density curve is drawn whether by eye or computer, it may be said of the maximum density that it is a “best fit” value for all the soil samples that were used in plotting it. The mathematical value for a maximum density as given in formula 15 may not produce an exact duplication of that from a normal curve but it fairly accurately represents the actual sample tested to give the values D_d and W_d and will certainly give a value for n_m which can be used to dictate the value for n_f to be specified for the field.

We have now a reasonably reliable means of obtaining a maximum density or n_m porosity by a single “one-shot” method and the writer would strongly suggest that values of n_m obtained by normal moisture density tests and that by employing equation 15 be compared in future to prove or otherwise the validity of the mathematical approach.

If field relative compaction is still the criterion for density, a single 5kg sample from the point of test tested at it's natural moisture content (which must unfortunately still be determined) will give a D_d and W_d from which the value of n_m can be calculated. It is suggested that the “one-shot” method be seriously considered in future.

4.5 Suggestion No. 5

A grid drawn up with the values $\frac{D}{G}$ and WG as the axis in place of the conventional Density (D) vs moisture (W) will be far more informative when a moisture density curve for different materials is plotted as it indicates directly a measure of strength that can be expected in the compacted soil. A graph as shown in figure 4 is suggested as this will indicate almost without effort the type of strengths that can be expected from the soil tested.

A few examples of the value of this chart are presented here:

Assume a given soil is compacted which gives the following test data:

$$D_d = 1.988\, t/m^3; G_{bk} = 2.65 \quad W_d = 3.77\%$$

From this we get: (subscripts omitted for simplicity)

$$\frac{D}{G} = \frac{1.988}{2.65} = 0.75 \quad WG = 2.65\,x\,0.0377 = 0.10$$

Referring to figure 5, if $\frac{D}{G}$ = 0.75 and WG = 0.10 are plotted it will fall on a dry leg contour which represents a CBR of 45 for the material densified at 1.988 t/m^3 and at a moisture content of 3.77%.

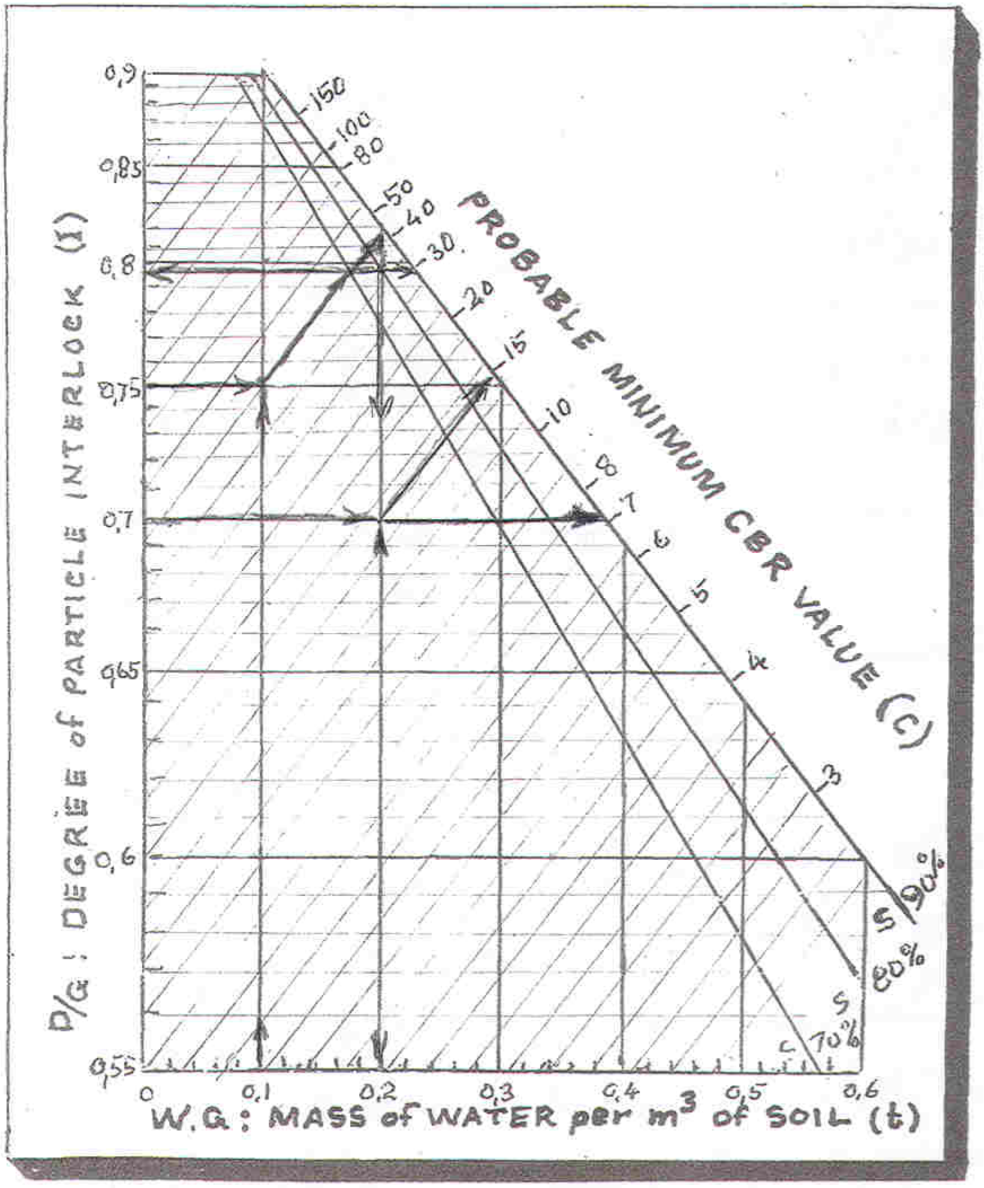

Figure 5. Using the strength diagram to estimate maximum densities, unsoaked CBR and soaked CBR values.

If the maximum density is to be estimated, follow the dry leg until it cuts the S = 70% wet leg. (At this point the soil has reached it's maximum density (see Figure 2) and $\frac{D}{G}$ = 0.798 i.e. D_m = 0.798 x 2.65 = 2.115 t/m^3.

If this $\frac{D}{G}$ ordinate is followed by going right horizontally until it reaches the S = 90% wet leg, the CBR is read off as 30 which is the soaked CBR for this soil at 100% maximum dry density of D_m.

Where this D_m ordinate cuts the S =80% wet leg this point represents the OMC for this density and can be read off where WG = 0.2 i.e. W = 0.2/2.65 = 7.55%

If this soil was compacted by means of a lesser effort to say 1.855 t/m^3 at the same OMC of 7.55% it's unsoaked CBR at this moisture content can be assessed as well as it's soaked CBR at 1.855 t/m^3. Here $\frac{D}{G} = \frac{1.855}{2.65} = 0.70$. The strength contour or dry leg at this point for $\frac{D}{G}$ = 0.70 and WG = 0.2 this shows a CBR unsoaked as 14. If this ordinate is followed horizontally till the S = 90% wet leg is reached the soaked CBR value is read off at 7.

It is evident from the above exercises that the $\frac{D}{G}$: WG : CBR diagram can give a vast amount of information and that extensive testing procedures can now possibly be eliminated.

4.6 The CBR Scale

The scale representing the CBR values along the S = 90% line in Figures 4 and 5 is based on the best information that could be gleamed from the COLTO minimum specifications for soil group strengths and from which the relationship given in equation 20 was prepared.

The writer would be grateful if testing laboratories where CBR and moisture density tests are performed would undertake to forward some of these results to him (no identities or further information attached) so that this scale may be confirmed or amended if necessary bearing in mind that this scale represents probable minimum values.

5. CONCLUSIONS AND RECOMMENDATIONS

The writer has attempted to highlight some of the lesser known or developed relationships of soil properties which is sincerely hoped will lead to further research and improved methods of density control in the not too distant future. It would be most welcome if these ideas and suggestions put forward would foster further research in the field of soil compaction and strength assessments. Soils being by their very variable nature will naturally show the odd exception but that is what makes SOIL ENGINEERING a very interesting pursuit and not just a dry as dust subject.

The main conclusions that are drawn are:

- Particle interlock, or porosity, is a vital determinant of layer strength and consequently the relative density of soil particles should be determined as part of the indicator tests.
- Compaction in the field should be evaluated in terms of a minimum porosity.
- Maximum achievable field density is related to the porosity of each of the TRH14 granular method 9 classification.
- A graphical solution for evaluation, the effect of both moisture content and compacted density on CBR will allow evaluation of all these parameters from a single moisture density determination.

6. ACKNOWLEDGEMENT

The writer wishes to express his thanks to:

Prof Alex Visser for advice and

Mrs Wendy Burdzik for so ably transforming a hieroglyphic Manuscript into an acceptable and readable document.