Short Communication

Prediction of Compaction Characteristics of Soils from Index Properties

by

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Introduction

Placement of fill materials and compaction constitute a major part in Civil Engineering constructions. The stimulating work by Proctor (1933) developed a unique relationship of dry density of soils achieved under a particular compactive effort with the placement moisture content. Due to compaction, dry density, strength, deformation and permeability characteristics of the fill soils are considerably improved. Standard Proctor's compaction tests are extensively used by the engineers to determine the dry density for a particular fill soil, that can be achieved at different moisture contents with a particular compactive effort. Placement moisture content may be dry or wet of optimum moisture content, depending on the functional purpose of the placed fill (Winterkorn and Fang 1975).

The degree of compactness obtained in the field is measured by the relative compactness, the recommended value of which for different Civil Engineering projects ranges between 95-100% (Nayak, 1982). However the achieved dry density in field may vary from place to place even in a comparatively small area due to variation of non-uniform compaction or change in type of soil or variation of placement moisture content. In projects of wider extent like road construction, due to large variation of type of borrow materials available for fill, very random variation in achieved density may result, under same compactive effort system chosen. In such cases, it is quite difficult to get representative information like placement moisture content and dry density from limited compaction test results, unless a very large number of tests, with all different types of soils, are performed involving large cost and time.

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The moisture content-dry density relationship for a particular soil is unique and parabolic in nature. Again the compaction properties of any soil is greatly influenced by its plasticity. The plasticity limits, although, were derived originally for purposes of soil classification, have been attempted in recent years to correlate with various soil properties. Such correlations, however, become more meaningful when the mechanisms, controlling the plasticity properties of soil and the associated behaviour are properly understood (Rao and Rekhi 1977). On the basis of a study on large number of soils, in Ohio, of different consistency, Krebs and Walker (1971) indicated difinite relationship between liquid limit and plasticity indices with maximum dry density and optimum moisture content. Attempts have also been made by Ingles (1974) to relate the optimum moisture content and dry density with liquid limit and plastic limit of a large number of U.S. soils. It has been shown qualitatively that an increase of liquid limit and plasticity index is generally accompanied by increase of optimum moisture content and decrease in maximum dry density. The consistency limits like liquid limit and plastic limit can be obtained in quick time and much less cost without requiring much expertise, on representative samples, both in field and laboratory. Any correlation of liquid limit and plastic limit with Proctor's compaction curve in predicting the placement moisture content and achievable dry density, may be very significant in cases of placement of fills of widely varying consistency limits, over large tract, by reducing the time of test, cost and expertise level.

In this paper, an attempt has been made to develop correlation between the plastic properties of inorganic finegrained soils of alluvial nature and the Proctor's dry density at various placement moisture content in terms of liquid limit and *PI/LL* ratios. A computer program has been developed to fit a polynomial for the compaction curve, introducing three parameters, which can be used to predict not only the maximum dry density and optimum moisture content, but the complete Proctor's compaction curve.

Compaction Curve

The moisture content-dry density relationship obtained from Proctor's standard compaction tests for any soil, indicate a parabolic relation with a peak point corresponding to optimum moisture content and maximum dry density. Such a relationship for any soil can be expressed as

$$\gamma_d = A + Bm + Cm^2 \qquad \ldots(1)$$

where γ_d = dry density in gm/c.c.

m = moisture content

A, B, C = parameters

At the peak, for the dry density to be maximum

$$\frac{d\gamma_d}{dm} = 0 \qquad \text{...(2)}$$

From Eqs. (1) and (2), the optimum moisture content can be written as:

$$m_o = -\frac{B}{2C} \qquad \text{...(3)}$$

and the maximum dry density as:

$$\gamma d_{max} = A - \frac{B^2}{4C} \qquad \text{...(4)}$$

Large number of inorganic soil samples of alluvial nature were collected from various locations around Calcutta. Standard Proctor's compaction tests (I.S. 2720 Part VII—1980) were performed in the laboratory on each of them for different moisture content to determine the corresponding achieved dry density. From plotted curves of moisture content vs. dry density, optimum moisture content and maximum dry density were obtained for each of the soil samples. To facilitate easy theoretical computation, a computer program was developed to express the compaction curve as a polynomial (Eq. 1) by curve fitting by least square method. Experimental data of moisture content and dry density were utilised to determine the parameters A, B and C of the fitting polynomial for each soil samples. Once the values of the parameters A, B and C are known for any soil sample, the optimum moisture content, maximum dry density and also dry density at any placement moisture content can be computed using Eqs. 3, 4 and 1 respectively. In the following sections, it has been further shown that these parameters can be predicted from the plastic properties of soil.

Results and Discussion

For all soil samples, liquid limits and plastic limits were also determined (I.S. 2720—Part V) in the laboratory. Optimum moisture content and maximum dry density data have been plotted against liquid limits of soils and shown in Figs. 1 and 2 respectively. Numbers shown against plotted experimental points indicate the *PI/LL* ratio of the particular soil sample. In these figures, variations of *OMC* and maximum dry density against liquid limit are shown for different values of *PI/LL* ratio varying from 0.25 to 0.57. The value of the ratio has been indicated within circles against each curve drawn. It has been observed that for same *PI/LL* ratio, optimum moisture content increases while maximum dry density decreases with increase in liquid limit, Further, for same liquid limit, with the increase in the value of the ratio *PI/LL*, optimum moisture content decreases, but maximum dry density increases. In other words, for same liquid limit, lesser is the plasticity index, greater is the optimum moisture content and lesser is the maximum dry density. Values of optimum moisture content and corresponding maximum dry density reported by Kreb and Walker (1971) are also plotted against liquid limit indicating the *PI/LL* ratios in Figs. 1 and 2. These data follow the same trend and substantiate the general findings presented from this study.

The values of the parameters *A*, *B* and *C* obtained from fitting polynomials for the compaction curves have been plotted against liquid limit in Figs. 3, 4 and 5 respectively. The values of *PI/LL* ratios are also indicated against the plotted points. Through the plotted points, attempts

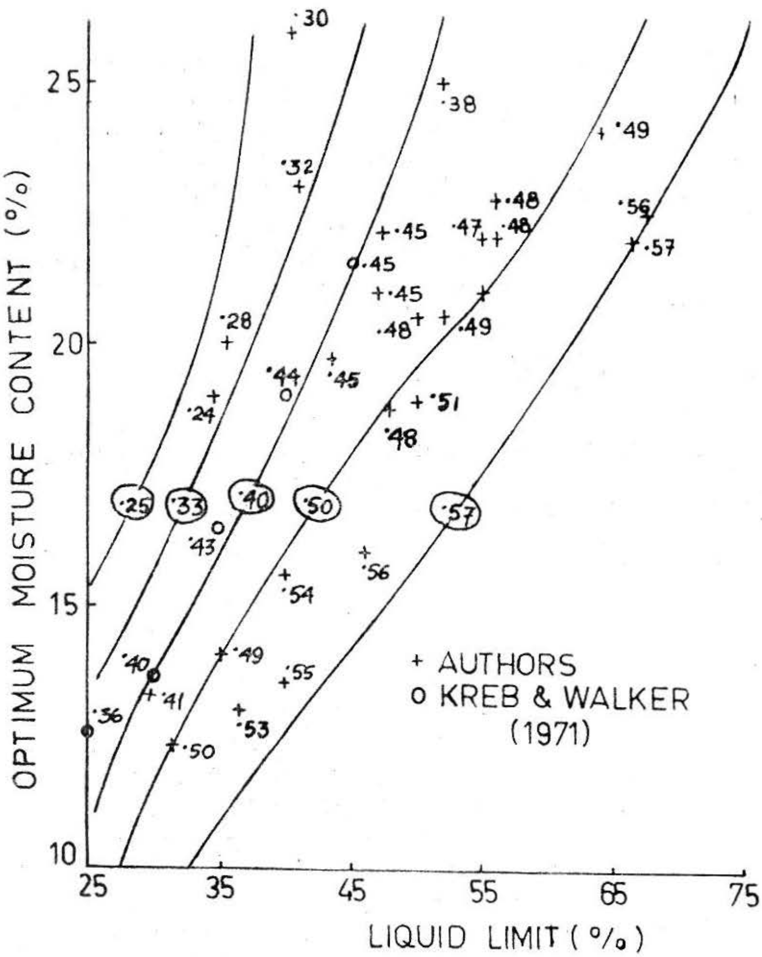

FIGURE 1 Variation of Optimum Moisture Content with Liquid Limit for Different PI/LL Ratio

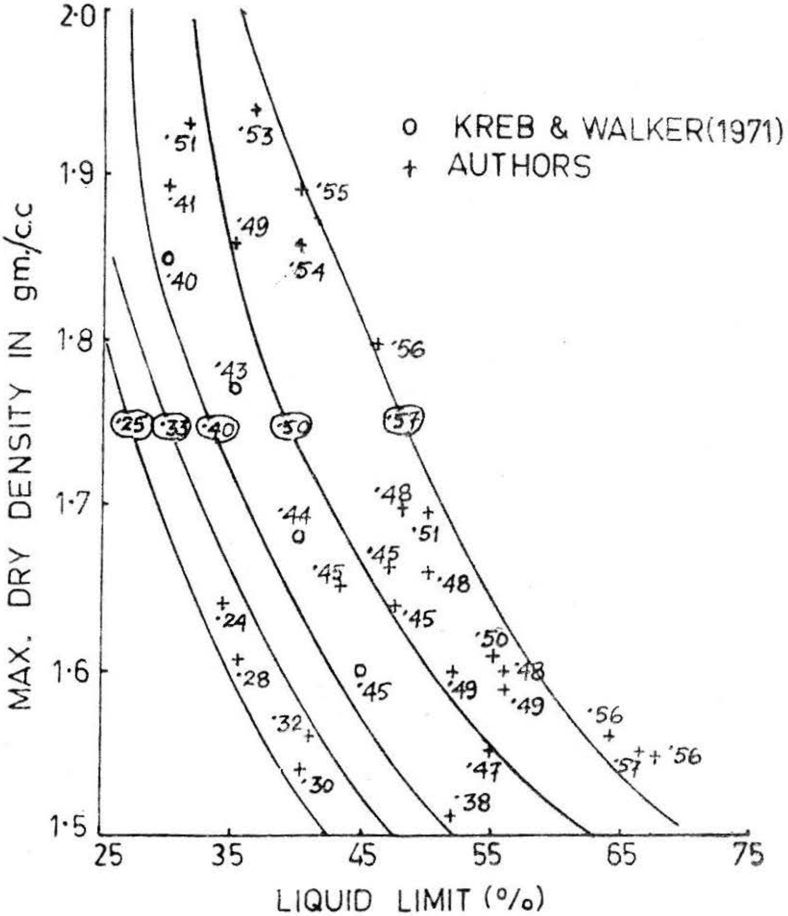

FIGURE 2 Variation of Maximum Dry Density with Liquid Limit for Different PI/LL Ratio

have been made to draw the variations of the parameters for equal *PI/LL* ratios of 0.25, 0.33, 0.50 and 0.57 respectively. Figure 3 reveals that for same *PI/LL* ratios, the parameter *A* decreases to a minimum value and then increases with increase in liquid limit. However for same *LL*, the parameter *A* increases with decrease in *PI/LL* ratio. This indicates that for a given liquid limit, higher the plasticity, lower is the value of *A*. It is interesting to note from Eq. (1) that when $m = 0$, $\gamma_d = A$ numerically. Thus it is seen from Fig. 3 that at same *LL*, for soils having greater plasticity lower will be the dry density, *i.e.*, dry density increases with decreasing plasticity. Further from Fig. 3 it appears that for soils having $LL > 40\%$ the parameter *A* for a particular *PI/LL* ratio tends to assume very large value. But with increase of *LL* the plasticity index also generally increases

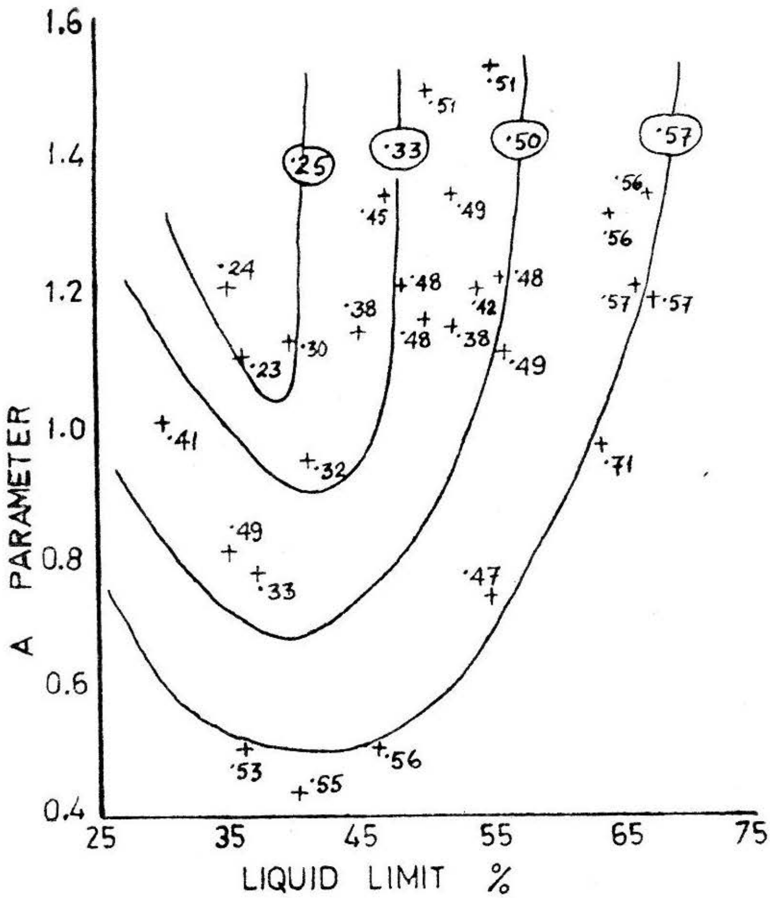

FIGURE 3 Variation of Parameter A with Liquid Limit for Different PI/LL Ratio

when A value will be obtained corresponding to higher values of PI/LL ratio. Further for clays it is generally observed that plastic limit (PL) varies in a small range compared to variations of liquid limit, and PI/LL ratio for different inorganic clays lies in close range of 0.44 to 0.62 as reported by Yong and Workentin (1975).

It can be observed from Fig. 3(*b*) that the parameter B decreases with increase of liquid limit at same PI/LL ratio. But at same LL, the value of B increases with the increase of plasticity of the soil. The values of the parameter C is always negative, as it is also evident from Eq. (3). Qualitatively the variation of the parameter C (Fig 5) with LL and PI/LL ratio is similar to that of the parameter B.

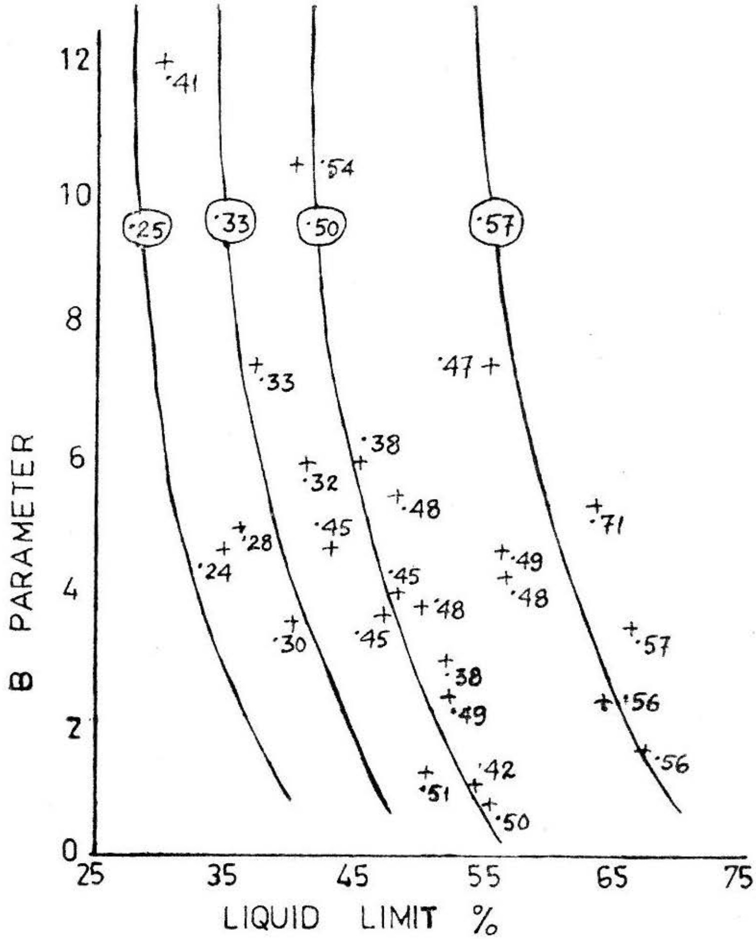

FIGURE 4 Variation of Parameter B with Liquid Limit for Different PI/LL Ratio

For further understanding the range of consistency limits and indices for various soils, on the basis of the modified plasticity chart (Fig. 4) of Menard and Broise (1975) Fig. 5 has been drawn to classify soils in terms of *LL*, *PL* and *PI/LL* ratio. It can be observed that any soil type will have definite range of plastic properties. In general, most of the soil types that are used for compacted fills in embankments will lie around '*A*—line'. For these soils, *PI/LL* ratio wil approximately range between 0.25 to 0.6 and *LL* will lie between 30 to 80%. Therefore, for all practical soils of alluvial nature, the values of parameters *A*, *B* and *C* will lie within the range of Figs. 3, 4 and 5.

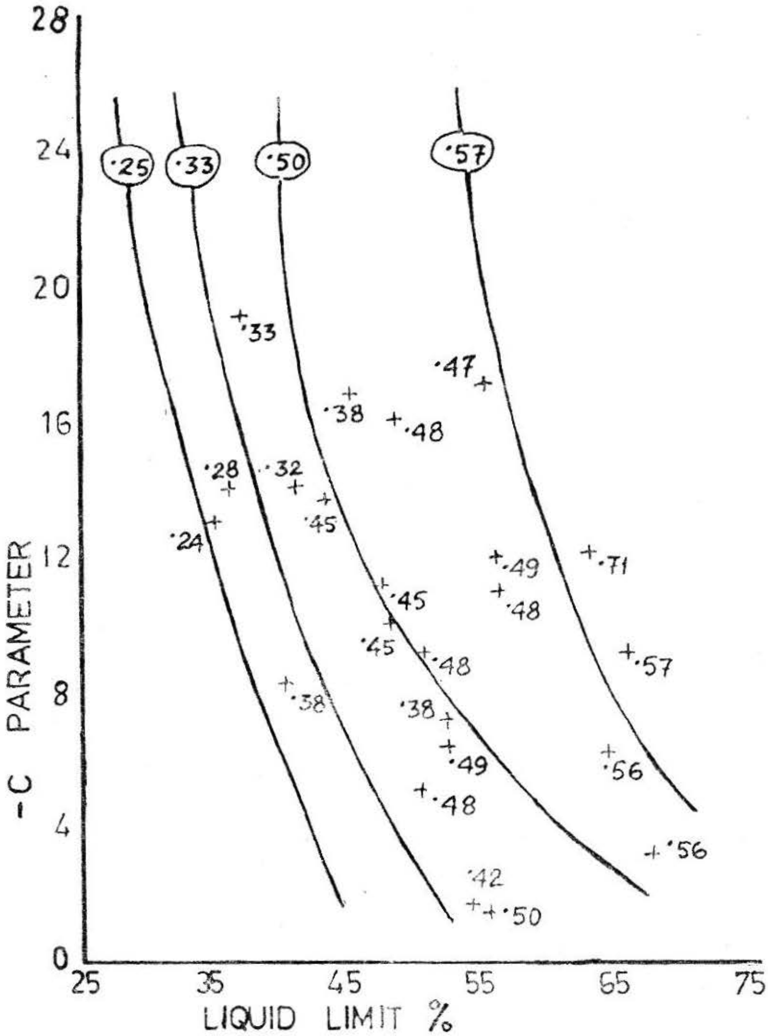

FIGURE 5 Variation of Parameter C with Liquid Limit for Different PI/LL Ratio

Since the values of *LL* and *PI* for any soil can be determined conveniently in a short time, one can use these consistency limit values to get approximate values of the parameters *A*, *B* and *C* from Figs. 3, 4 and 5 respectively. Once these parameters are shown, the optimum moisture content, maximum dry density and dry density at any placement moisture content, which are normally to be obtained experimentally from compaction curve of any soil, can be predicted easily using Eq. (3), (4) and (1) respectively. Alternatively optimum moisture content and maximum dry density can also be predicted using Figs. 1 and 2 respectively.

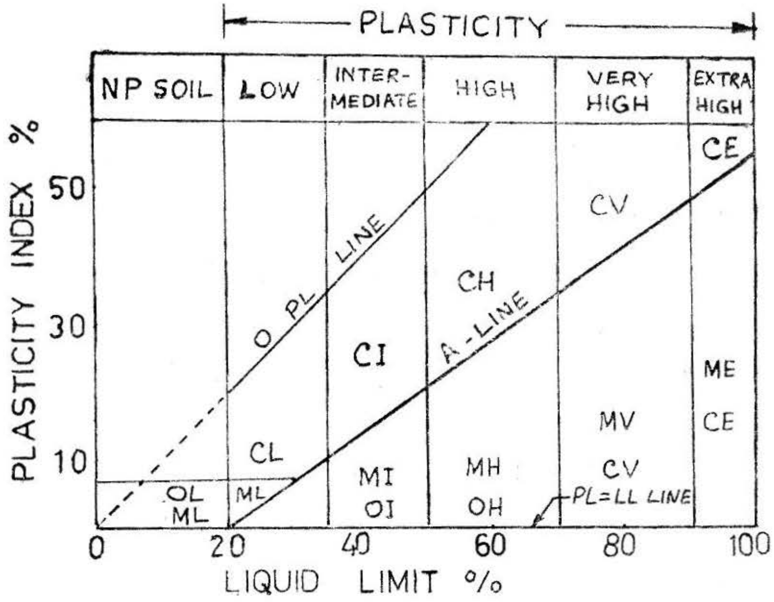

FIGURE 6 Modified Plasticity Chart (after Menard and Broise, 1975)

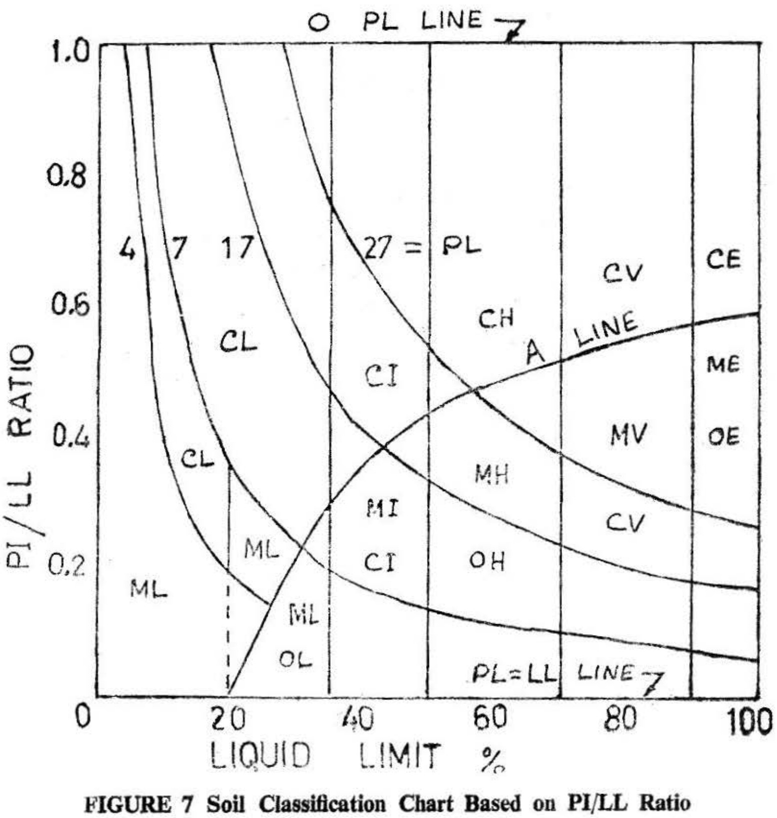

FIGURE 7 Soil Classification Chart Based on PI/LL Ratio

Conclusion

Correlations have been developed for optimum moisture content and maximum dry density of compaction characteristics of any soil, in terms of its liquid limit and *PI/LL* ratio. These correlations can be used conveniently to predict *OMC* and γd_{max}, when *LL* and *PI* of any soil are known. The trend of variation of the compaction characteristics presented by the authors compares well with the reported data.

Moreover, a theoretical approach has been presented by introducing three parameters *A*, *B* and *C* which can conveniently be obtained, when *LL* and *PI* of any soil are known. These parameters can be used to predict approximately the moisture content-dry density relation of the soil.

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