Marchetti Discussion to Leonards and Frost paper :

"Settlements of Shallow Foundations on Granular Soils"
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SETTLEMENT OF SHALLOW FOUNDATIONS ON GRANULAR SOILS[a]

Discussion by S. Marchetti[7]

The authors offer a significant contribution on a topic traditionally of great interest to soil engineers. The paper touches directly or indirectly on a number of key issues, some of which are discussed herein.

STRESS PATH DIFFERENCE EFFECTS

Two of the main concerns expressed by the authors are (1) The dilatometer loads the soil horizontally, while most foundations load the soil vertically; and (2) the Young's modulus E may be more appropriate than M when dealing with isolated footings. Such concerns are justified, but, as implied also by the authors, they are dwarfed by the far greater concern over the complex stress path pattern during penetration. The writer feels that a decisive advance of the conceptual framework will be possible only when a theoretical modeling of the blade penetration will be developed. Such modeling might become available in the near future (Huang 1988) but, until then, the interpretation will have to rely on empirically established correlations (also at the base of the authors' method).

POTENTIAL OF PREDICTING SETTLEMENTS BY DMT

The aforementioned recalled concerns warrant serious reconsideration of the background overall reasons at the base of the optimistic expectations—expressed by the authors and shared by the writer—about the DMT settlement predictive capability.

One direct base of optimism is the increasing number of case-histories documenting satisfactory agreement between DMT predicted and observed settlement [for sands: Schmertmann 1986b; Hayes 1986; Sallfors 1988; Lacasse and Lunne (1986)].

Another base of optimism (less direct, but substantiated by a much larger experimental base) is the reported success in predicting settlements by SPT. For example, the systematic analysis of Burland and Burbidge (1985), of over 200 cases of settlement in granular soils, led to an interpolated formula whose structure indicates some kind of link *Nspt* to modulus. This link is believed to be an important independent basis for expecting even closer predictions by DMT, for the following reasons:

1. A modulus-to-modulus correlation should be superior to a penetration resistance-to-modulus correlation.
2. The DMT involves an insertion less disruptive than SPT.
3. DMT provides nearly continuous measurements.
4. The E_D profile is highly reproducible. (Indeed E_D is one of the very few measured deformation parameters that operators are unable to alter.)
5. Since the DMT membrane diameter is several (~4) times the thickness of the blade, the expansion involves loading sand even beyond "the most distorted zone" (say half blade thickness) (Fig. 10). This is a very peculiar—often overlooked—feature of DMT.
6. The additional index k_D, providing at least an approximate indication of stress history, offers nonsubjective guidance in the choice of the factor R_M in $M = R_M \cdot E_D$. (Telling an engineer to reduce in OC sands the calculated settlement by say 2 or 3 may be of little help given the difficulty, in many cases, of discerning NC from OC sands.)

SPLITTING THE NC/OC SETTLEMENT CONTRIBUTIONS

One of the steps in the authors' suggested procedure requires identifying p_c' and splitting in two the load interval (as currently done with oedometer curves). However, the writer sees some difficulty in its application.

In the writer's experience, p_c' cannot be determined—by either of the two methods mentioned by the authors—with the definition necessary to justify a formal two-interval calculation. This not necessarily because of the approximate nature of the correlations. Many granular soils simply do not have

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[a] July, 1988, Vol. 114, No. 7, by G. A. Leonards and J. D. Frost (Paper 22591).

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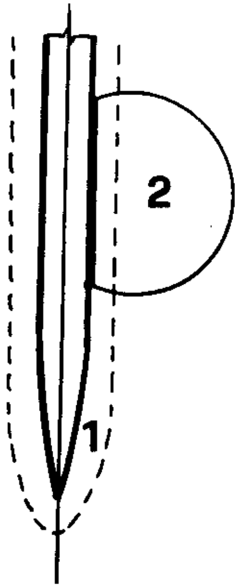

FIG. 10. Schematic Illustration of: (1) "Most Distorted" Zone; and (2) "Significant" Soil Bulb Tested by Membrane

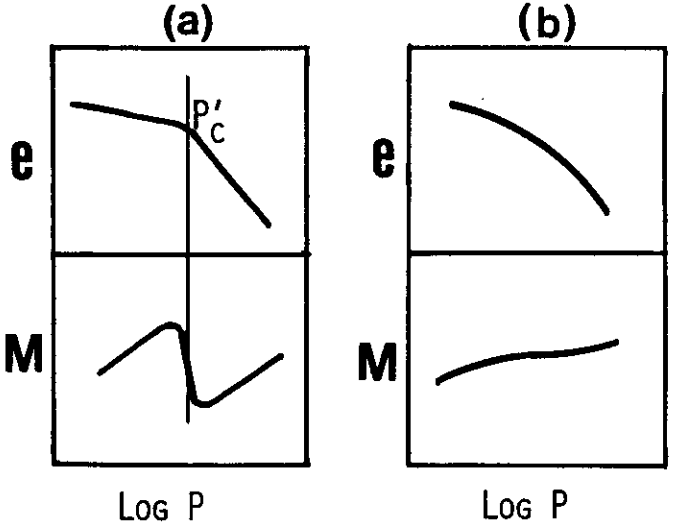

FIG. 11. Variation of e and M with Vertical Stress p in Presence/Absence of Well-Defined p'_c

a well-defined break in their in situ e-log$p$ curve (Fig. 11). Thus, the inaccuracy in the identification of the often elusive (in sand) p'_c may nullify the effort.

Another possible inconvenience of the proposed method is the assumed modulus discontinuity upon OCR = 1, which will not reflect the in situ M versus p curve in the (possibly numerous) situations of the type shown in Fig. 11(*b*). In such situations the M variation with p is moderate, and M can be used satisfactorily even over a substantial stress increment. Moreover, in "nearly NC" sands, considerable uncertainty (and difference in predictions) would derive from the inability (by any method) to tell OCR = 1 sands from OCR = 1.05 sands, leaving the user puzzled with the choice of the NC or OC correction factor.

In conclusion, the writer prefers, for general use, a unique average value of M over the whole stress interval, with $M = R_M E_D$, where R_M is a continuous (increasing) function of K_D [Marchetti (1980), well approximated, in sand, by the authors' Eq. 15].

Use of Calibration Chamber (CC) Results

The writer agrees with the authors about the useful indications obtainable from CC results. However, possible pitfalls should be pointed out in the direct transposition of CC results to in situ behavior. For example, freshly prepared CC sand specimens (especially if loose) have many unstable grain contacts, which are significantly stabilized by an even small prestress cycle, resulting in an "exaggerated" jump in "modulus" across OCR = 1.

Most natural sands have had ample opportunity in the past to improve their upon-deposition stability. Therefore, modulus variations across OCR = 1 of a natural sand are likely to be smaller and more gradual than those observed for a CC specimen (similar to saying that virtually all natural sands are at least slightly OC).

Therefore, CC results, in particular, the low D_r datapoints in the vicinity of the OCR = 1 discontinuity, should be carefully scrutinized to check their relevance to the specific aspect under study.

Corrections *Ed* for Insertion and Stress Path

The authors state that "the use of an approximate value R is superior to making no allowance whatsoever to account for the effects of disturbance and stress path on the modulus interpreted by DMT." The discusser would like to point out that the correction factor R_M in his 1980 paper was specifically meant to allow for these effects. Since R_M is an empirically determined factor, translating E_D to M, R_M incorporates—conceptually—all effects. Indeed, the E_D correction is an essential preliminary step before deriving any operative deformation parameter, which should then be derived from $M = R_M E_D$ and not from E_D.

The dependence of R_m from Kd expressed by Marchetti (1980) may be partly illustrated by Fig. 12. The K_D results (that the writer profiles routinely) show well-evident "K_D crusts" reflecting in all likelihood (though difficult to prove), overconsolidated sand crusts. For the high K_D values in the crusts, Marchetti (1980) provides R_M say 2 to 3. Theses values are similar to those proposed by the authors for OC sand. Thus, the difference is not in the

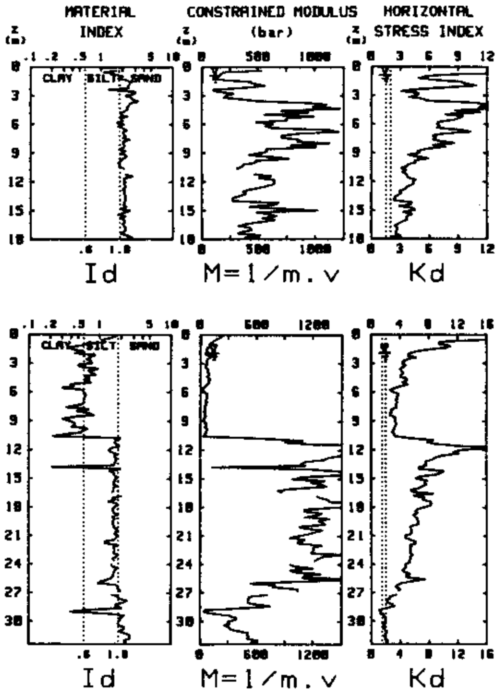

FIG. 12. Examples of "K_D Crusts" in Sand; DMT Results at River Po (Top), Verona (Bottom)

numbers, but in the fact that the discusser prefers the gradual R_M increase provided by his figure.

The discusser also feels that $R_M \cdot E_D$ should not be further factorized (as suggested by the authors) because this indication, derived directly from CC results, does not seem supported by the field settlement measurements available so far [Schmertmann (1986b) reporting an average ratio measured over predicted settlement—using $R_M \cdot E_D$—equal to 1.18].

ONE-DIMENSIONAL VERSUS THREE-DIMENSIONAL METHOD OF SETTLEMENT CALCULATION

The authors correctly point out that "settlements of isolated footings hardly occur under constrained conditions." Therefore, they suggest using E for isolated footings, and M for large rafts. The discusser obviously agrees, conceptually. However, for practical applications, the simple one-dimensional theory (Eq. 13) is favored. The reasons for this preference are illustrated with the help of the following remarks by Burland et al. (1977):

- The three-dimensional method (unlike the one-dimensional) involves ν and makes use of the horizontal stresses that "may be grossly over-/underestimated by theory of elasticity," while the vertical stresses "are surprisingly well predicted by simple elastic theory."

- "For most practical cases, the conventional one-dimensional method gives settlements that are within 10% of the three-dimensional calculated settlement, provided $\nu < 0.3$."
- "Errors introduced by simple classical methods of analysis are small compared with those (associated with the determination of deformation parameters). Hence, the emphasis should be on the accurate determination of simple parameters, such as one-dimensional compressibility coupled with simple calculations."

Thus, the gain in accuracy of three-dimensional versus one-dimensional is probably illusory, so that the one-dimensional method, being simpler and "conventional," may be preferable. On the other hand, if the three-dimensional analysis is required, M can be converted (at least formally) into E using the theory of elasticity, that, for $\nu = 0.25$, provides $E = 0.83\ M$ (a factor not very far from unity). Indeed, as observed by various researchers (Ladd et al. 1977), often M and E are used interchangeably in view of the involved approximation.

The previously quoted remarks by Burland make M an attractive deformation parameter. This is indeed one of the reasons why M was selected as the target deformation parameter in the DMT correlations.

For the reasons discussed, the value of M that the discusser would presently use with the one-dimensional method (Eq. 13) is still the one obtained using the correlations in his 1980 paper.

APPENDIX. REFERENCES

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Discussion by J. H. Schmertmann,[5] Fellow, ASCE

The discusser agrees with the conceptual framework of the new, Marchetti dilatometer-based, sand-settlement analysis method proposed by the authors. It combines the 1970 strain factor method with the dilatometer E_D and M-values corrected for the effects of prestressing as determined from various types of laboratory tests, especially the recent, extensive, large-scale cali-

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