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Applications of Index Properties and Results of Subsoil Exploration to Soil Engineering Problems

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In recent years there has been an exponentially increasing use of routine tests in applied soil mechanics. Whereas academic research has branched off towards sophisticated testing, finite element analyses, and attention to somewhat special problems, the index tests that grew up with early soil mechanics have remained essentially untouched. Few users of such index properties and simple subsoil exploration results stop to worry about the very unpretentious beginnings implicit in the very test procedures and parameters intuitively defined. Most users shudder at the thought of having to take cognizance of the variabilities of soil types and behaviour through the dirtying and subjective procedures of inspecting test pits and handling the soil pat for visual-tactile observations. Moreover the language of communication imposed on the multitudes of users harnassed to the technological world must be numerical. And, finally, whereas about a decade ago there were still difficulties at recognizing or postulating any but the most clearly evident correlations between parameters, the indiscriminate use of statistical techniques has opened wide the doors to the determination of a variety of correlative functions which would provide the very tools eagerly sought, for direct computations on foundation engineering problems duly programmed.

The author submits the following considerations to careful consideration and discussion.

1. CONTINUING APPLICABILITY OF SIMPLE INDEX OBSERVATIONS

In most fields of scientific endeavour the technological advances of the past 20 years have clearly demonstrated that for many a purpose much better "sensory equipment" can be developed than that represented by our visual-tactile observation and primitive mechanical manipulations: the field of the biosciences may be one of the best examples. Moreover, certain new fields of engineering (e.g. ocean engineering, lunar soil investigations, etc.) have made it quite imperative to rely greatly or solely on indirect manipulation by specially devised sensory equipment. And, at least one intrinsic disadvantage to the sensory perceptions of the visual-tactile manipulation of soil must be emphasized: under routine conditions such manipulation and its observations are, ipso facto, under $\sigma = 0$ conditions, and do not include detection of the other influences such as chemical, etc.; the most transparent distinction between the intuitions of the trained soil mechanician and of the lay, centers around the latter's inability to visualize behaviours of the specimens when confined under external pressures, even light to moderate.

To what extent, therefore, it is valid to retain the early techniques of simple exploration and identification at the basis of our soil engineering?

It is herein postulated that the applicability of index observations will persist, although the present situation appears to require thorough overhaul. In the same way as biologically, neurologically, and culturally, we repeat ontologically all of "our past", each new soil engineer, and/or any experienced engineer in the face of each new problem, must in some way retrace the same basic steps. Presumably, important evolutionary change must needs be accomplished by superposing new systems on top of old ones, reminescent of Ernst Haeckel's doctrine called "recapitulation". On the other hand, apparently the usefulness of such a procedure and experience-acquisition cannot but remain extremely subjective and egoistic: unfortunately it is part of our neurological and cultural inheritance that our visual cognitive capacity is many many times better than our capacity at communicative description; for instance, any one is able to recognize, remember, and distinguish, thousand times more faces than he is able to portray for communication to others.

Finally, it must be warned that even within the strictly personal experience-acquisition, the dominantly egoistic note reveals itself in yet another facet: we only note and digest and remember what was really significant in some manner; our capacity to recognize faces is disparately poor in the case of "others" in comparison with those that are within a narrower radius of influence on ourselves. By the same token, our experience with index observations and soil behaviour is all the more marked in connection with significant problems that affected us.

Many an example may be mustered to confirm the fact that to us the information content from a coloured photograph far outstrips that of any boring log packed with descriptions and test indices.

2. POINTS OF NOTE AND OF CAUTION

Having accepted the continuing applicability of index observations above mentioned, one must immediately alert the practising soil engineer on many points of exception and caution, some of which may be herein summarized.

2.1 Arbitrary sample manipulations behind routine tests

The test routines that were independently standarized include very significant arbitrary manipulations that alter the composition of the same soil as it enters in different tests. Fig. 1 summarizes, just as an example the ASTM Standards, and dispenses further comment. The net result is that many attempts at statistical correlations prove frustrating or misleading.

2.2 Design prescriptions as distinct from correlations

In many a case, index properties have proven amply satisfactory for simple and safe design prescriptions despite the lack of correlations supporting predictions of behaviour. As has been repeatedly emphasized, design is often based on upper and lower bounds of predictable behaviour, and or anticipation that such bounds will not be exceeded.

2.3 Obvious correlations, but with too wide a scatter

The practising professional has often been enticed to use some rather sweeping and obvious correlations, which, however, involve too big a scatter to serve for a specific foundation solution without overlapping onto alternate solutions of narrower band of uncertainty that would prove more economical: the change from one feasible solution, to preference for another, frequently occurs within a narrower band of dispersion. For instance, obviously the compressibility of a material composed of mineral grains and pores should in first degree approximation be a function principally of porosity, and a single correlative equation between compressibility and porosity can apply to all materials: the question will be the dispersion that any given case may present in relation to the average equation. The confidence limits of such equations have seldom been furnished, and would generally prove too wide for satisfactory engineering decisions of responsability.

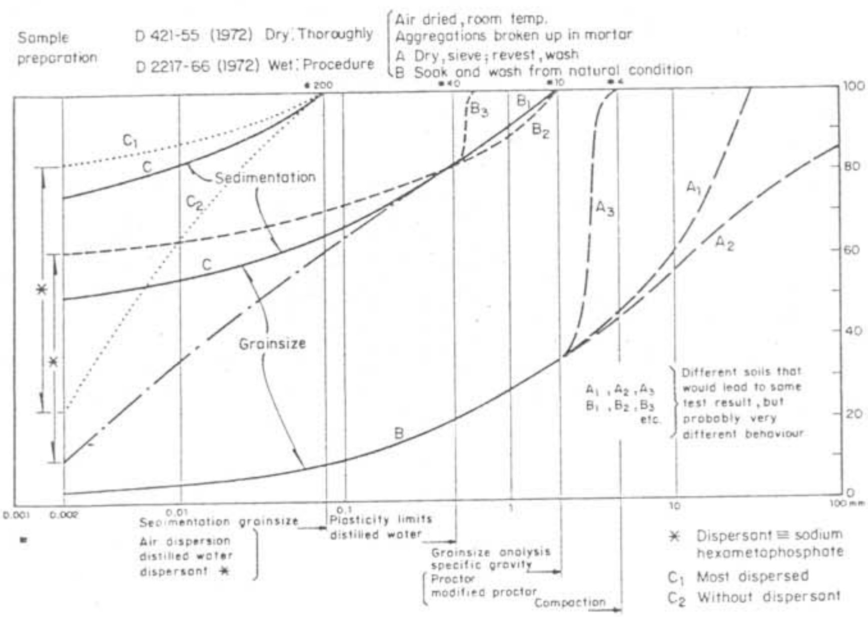

Fig 1. Differentiations imposed on soil in routine tests

Similarly since denser materials present simultaneously a lower compressibility and a higher strength, a correlation could be put forward directly between strength and incompressibility: what would be its practical usefulness towards decisions between alternate engineering solutions?

2.4 *Correlations regarding parameters questionably defined*

It must be recognized that in any process of technological development, not every well-intended innovation would automatically chance to be ideally suited to the purposes envisaged. Both the definition of the parameter and the test procedure established for its determination may require questioning and optimization. For instance, a good proportion of the disagreements regarding correlations with such an index as the relative density of sandy materials derives in part from the fact that the very definition of the index would depend on the hopeful and statistically difficult laboratory determination of extreme values (maximum and minimum void ratios), and further from the inapplicability of the test procedure, devised for creating the loosest condition, in any soils but those of relatively uniform grainsize distribution.

Problems of erosion, piping, liquefaction, and similar, capable of progressing from localized extreme conditions, should be examined critically with respect to the dispersions of test determinations, affected by extreme value statistics. (de Mello, 1977).

2.5 *Frequent statistical correlations not aligned with theoretically supported trends*

One must recognize that there is a very frequent tendency to establish presumed correlations without any consideration of the weight of accumulated experimental and theoretical evidence that indirectly would render such correlations untenable. Commonly the engineering need is most seductively met by single-parameter correlations, frequently linear: even when established by statistical regressions, if theoretical reasonings are not employed for establishing the adequate trends of the function at play, the net effect is to restrict the credibility of the correlation to the specific range of the data employed. True respect for statistical techniques would not merely investigate regression equations and coefficients of correlation, at random, in search for the conditions of best fit; theory and its multiple crosslinkages experimentally confirmed represent a strong Bayesian support for prior stipulations of likely functions to be fitted to the data. If a different function appears strongly supported, its effects on possible revisions of theoretically held conceptions should be examined.

3. BASIC SUBSOIL EXPLORATION

It has been emphasized that preliminary subsoil exploration will probably continue to rely on combined techniques employing perforation-rugged representative sampling-consistency evaluation by such index tests as the Standard Penetration Test SPT. Many a more refined technique has already come into use for specific purposes, but it continues to appear that such tests will stand as complements to, and not as substitutes for, the exploratory boring. Such have been the corner stones of foundation engineering to date, based on the precept that "in order to apply a theory to a soil problem we are compelled to replace the real soil profiles by simplified ones consisting of a small number of homogeneous layers, and to assign to each one of these layers a single set of soil constants to be derived from the results of soil tests by means of some process of averaging" (Terzaghi, 1940).

Prescriptions and correlations in use will thus be predominantly connected with classification index properties regarding the type of soil, and penetration resistance regarding the consistency or density of the soil stratum. It is widely recognized, however, that because of such criticisms as summarized under item 2 above, the attempt to quantify geotechnical parameters is frequently very poor indeed, even by great specialist consultants and when covered by routine index tests, if somewhat peculiar regional soils are involved, situated beyond the specific context of experience of the specialist: in other words some of the present index observations can be misleading if there is no context of visual correlation with the results of fundamental tests and prototype behaviour.

4. SOME PUBLISHED PRESCRIPTIONS AND CORRELATIONS: VERY BRIEF DISCUSSION

In Figs. 3 and 4 an attempt is made to summarize, on the one hand the principal soil exploration index properties that are estimated consciously or subconsciously by the foundation engineer, and on the other hand, the main foundation engineering problems that have to be equated on the basis of well-known parameters. Any such charts cannot avoid including a considerable proportion of subjective evaluation: however, at the risk of an inevitable degree of arbitrariness, an effort is being made to suggest highly simplified criticisms, prescriptions, or presumed-correlations, in order to advance to the utmost the props that might be mustered, and to serve as the basis for debate, denial, and, hopefully, catalysis for forthcoming formulations where the needs appear great. The summary comments that follow may hint that in professional practice very little of the conventional index parameters proves of direct applicability, without too great a dose of "correlation factor intuitions" associated with local experience with specific soils and foundation types and loadings. Such is, indeed, the author's experience and feeling. Is not the time ripe for the thorough overhaul of early practices that have served their magnificent purpose?

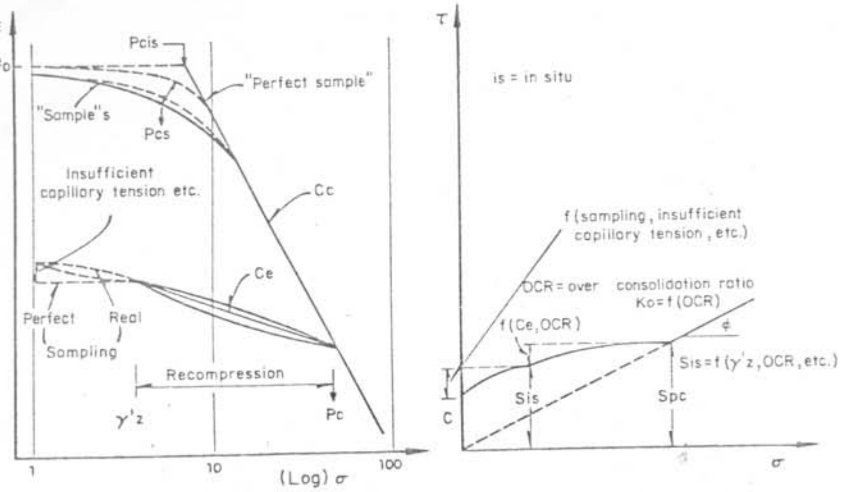

Fig 2. Classic key for seeking indications on compressibility and resistance parameters

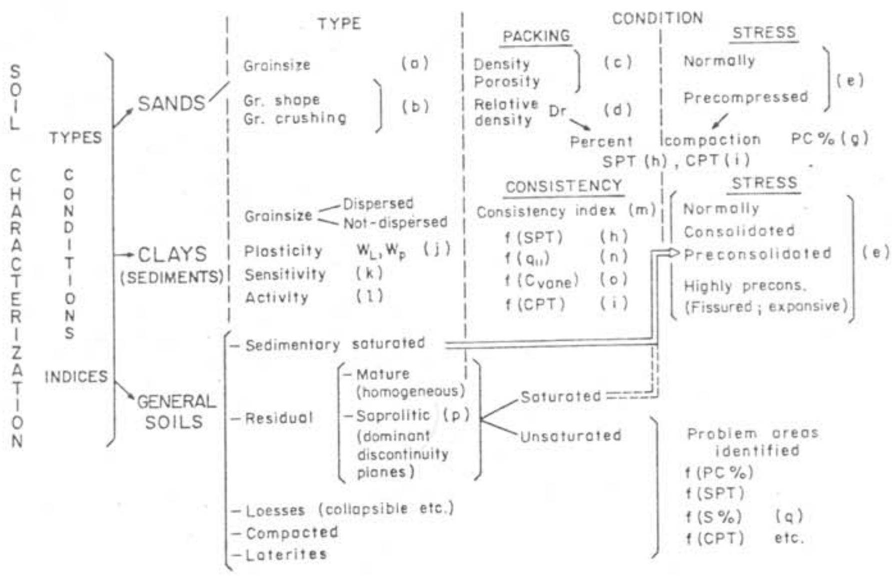

Fig 3. Chart identifying dominant index properties of subsoil and how estimatable

Fig 3. Comments

a- GRAINSIZE	CORRELATION PROPOSED (e.g. dos Santos (1953): not used
b- GR. QUALITY	RECOGNIZED IMPORTANT but no PRESC. or CORREL. known
c- DENSITY	EASILY ESIMATED
d- Dr	POOR TEST DEFINITION / PROCEDURES) WIDE DISPERSIONS NOT DOMINANTLY OR GENERALIZABLY SIGNIFICANT SUBSTITUTE BY PC % $\approx$ (81 $\pm$ 2)% + (0.2 $\pm$ 0,015) Dr
e- SAND PRECOMP.	NO INDEX TESTING AVAILABLE: MUST INFER FROM OVER-AND-UNDERLYING CLAYS. VERY IMPORTANT TO BEHAVIOUR
g- % COMPACT.	APPROX. INDICATIONS AVERAGE BEHAVIOURS: POORLY DISCRIMINATING. FILLS 80 $\lessapprox$ PC $\lessapprox$ 108. FOR PC $\approx$ 97%, 10 $\lessapprox$ SPT $\lessapprox$ 15 CLAYEY SOILS COMPACTED SOILS $p_c \approx$ f(PC)
h- SPT	V. MANY PRESC. AND CORREL. PROPOSED, MOSTLY EXTRAPOLATED TO ERRORS. PRINCIPAL CORRECTIONS DUE TO IN SITU STRESSES. ONLY INDICATES ϕ IN SANDS AND c IN LOW SENSITIVITY CLAY (e.g. qu $\approx$ 2c $\approx$ SPT/6 to 10 kg/cm^2) CORRELATIONS ON DEFORMABILITY INEVITABLY VERY INDIRECT e.g. CPT kg/cm^2 $\approx$ 4 SPT
i- CPT	MANY USES, CORREL. AND PRESC. BASICALLY CPT $\approx$ f(stength) e.b. IN CLAYS 10c $\lessapprox$ CPT $\lessapprox$ 20c IN SANDS USED FOR SETTLEMENTS, CPT $\approx$ f(E) HIGHLY DISCRIMINATING
j- PLASTICITY	CORRELATIONS e.g. Cc $\approx$ 0.009 (wL - 20) and similar: check; wide variations $cp_c \approx$ 0,11 + 0,0037 PI questionable, debated: basis c $\approx$ 0,5 qu? COMPACTED SOILS $Cc^c \approx$ 0,002 (wL + 63) or better Cc $\approx$ 0,21 (2,70 - γdmax. PROCTOR).
k- SENSITIVITY	OBVIOUS QUALITATIVE INFLUENCE - NO PRESC. OR CORREL. AVAILABLE
l- ACTIVITY	QUESTIONABLE INDEX, SAMPLE MANIPULATIONS (FIG. 1) AND RATIO. QUALITATIVE INFLUENCES OBVIOUS. NO PRESC. OR CORREL.
m- CONS. INDEX	OBVIOUSLY USELESS EXCEPT IN CLAYS OF LOW, *CONSTANT* SENSITIVITY, COMPARISONS WITHIN STRATUM
n- qu	HAS DOMINATED DEFINITION OF CLAY STRENGTH. VERY MUCH AFFECTED BY ABILITY CAPILLARY TENSION PROVIDE UNDISTURBED SPECIMEN, AND BY SENSITIVITY. PESSIMISTIC ASSESSMENTS PRINCIPALLY DUE TO UNSATURATION, SANDY FRACTION, HIGH STRESS RELEASE, etc.. (FIG. 2)
o- c_{VANE}	HIGH EARLY EXPECTATIONS. CORRECTIONS INDISPENSABLE. GOOD FOR IN SITU STRENGTHS CLAYS S = 100% s = c
p- SAPROLITE	CARACTERIZATION MUST DISTINGUISH BETWEEN AVER. MASS (e.g.COMPRESSIBILITY) AND PREFERENTIAL RELIC PLANES (e.g.STABILITY, PERMEABILITY). GRANULAR BEHAVIOUR IN SITU EVEN WITH HIGH PLASTICITY INDICATIONS OF CONVENTIONAL (a), (b), (j), (k), (l) TESTS. NO KNOWN INDICES FOR VALID INTERFERENCES: VISUAL-TACTILE AND SPT USED FOR INTUITIVE ASSOCIATION WITH PROTOTYPE BEHAVIOR. PRESCRIPTIONS OF SEDIMENTS GENERALLY HAVE PROVED CONSERVATIVE. UNDISTURBED SAMPLING UNSATISFACTORY (n), VERY PESSIMISTIC
q- SATURATION	VERY IMPORTANT ASSESSMENT, WITH POROSIMETRY. BEST IN SITU BEHAVIORS 80 $\lessapprox$ S $\lessapprox$ 90% WITH MACROPORES. RISK COLLAPSE PROBLEMS S 80%. IN SEDIMENTS PORE DIAMS. $\approx$ 0,2 GRAIN DIAMS (?).

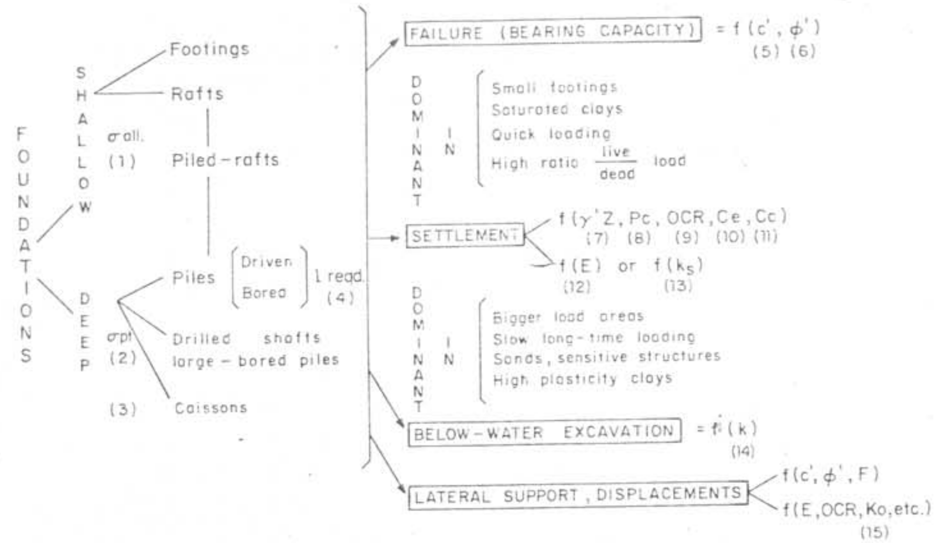

Fig 4. Chart identifying dominant foundation engineering problems; and necessary parameters how obtainable

Fig 4. Comments

1- σ all	PRESCRIPTIONS f(SPT) etc. SERIOUSLY MISLEADING, ONLY POSSIBLE IN S = 100%, s = c CLAYS, FOUNDATIONS CONDITIONED BY FAILURE: SIZE EFFECTS, SETTLEMENTS etc. CONTROL. TERZAGHI-PECK AND SIMILAR PRESCRIPTIONS MUST BE TRANSFORMED, EXAMINING SEPARATELY F OR BEARING CAPACITY, AND SETTLEMENTS: e.g. REINTERPRETING TERZAGHI-PECK-MEYERHOF ON SANDS IMPLIES ks t/m² per cm on 1 ft. plate ks ≈ 2(SPT-3), SAO PAULO PERSCRIPTIONS, PRECOMPRESSED CLAYEY SANDS etc. ks ≈ 3 SPT ≈ 10 √SPT.
2- σ pt.	PRESCRIPTIONS σpt ≈ n σall, 1,5 ≈< n ≈< 3 REQUIRES SIMILAR QUESTIONING: SO ALSO PRESCRIPTION σpt ≈ 1/10d, CPT kg/cm², d = pile diam.m. BORED AND DRIVEN PILES VERY DIFFERENT. BASE AND LATERAL FRICTION DEFORMATIONS VERY DIFFERENT. BASE SETTLEMENT IMPORTANT, f(E)
3- $s_{lateral}$	PRESCRIPTIONS f(SLEEVE FRICTION CPT) CONSERVATIVE ON DRIVEN PILES. BORED PILES DANGEROUSLY DEPENDENT ON CONSTRUCTION, STRESS RELEASE, etc, ESTIMATES f(c', φ', OCR, Ko, γ' z). FAILURE DEFORMATION CONSTANT ≈ 8 to 12 mm
4- pile length l required	SAO PAULO PRESCRIPTION, PRECAST CONCRETE, SPT EVERY m, COMPATIBLE SOILS, l SUCH THAT ΣSPT ≈ σconc. all., F = 1,5 PILE BORED PILE SIMILAR LOAD AND SECTION, l REQUIRED 30 to 50% BIGGER. (CF. ALSO AOKI AND VELLOSO 1975)
5- c', c 6- φ'	NO SIMPLE CORRELATIONS: MUST ANALYZE INTERRELATED PARAMETERS (CF. FIG.2). SANDS φ' f(SPT, z, φz, OCR) PROBABLE. CLAYS φ' = f(PI) PRESUMED; e.g. φ' 16,6 $e^{-0,011PI}$ WITH WIDE DISPERSION. GENERAL SOILS? NEED 2 EQUATIONS TO SOLVE FOR 2 UNKNOWNS
7- γ'z	EASILY ESTIMATED
8- p_c 9- OCR	ESTIMATED FROM c/p_c CORRELATIONS ? IMPORTANT DISTINCTION BETWEEN c and s_{is} OR sp_c (FIG. 2) COMPACTED CLAYEY SOILS p_c ≈ f(PC) e.g. for γdmax. ≈ 1,7 PROCTOR; log p_c ≈ 4,67 + 0,024 PC + 1,77 γdmax
10- Ce 11- Cc	MANY CORRELATIONS Cc = f(wL): improved Cc = f(wL, γ'z). Ce ESTIMATED (5-30%) Cc. QUESTION

12- E 13- ks	IN CLAYS PRESCRIPTIONS 100 c $\lesssim$ E $\lesssim$ 1000c MUCH QUOTED FOR c $\approx$ 0,5qu. IN SITU BEHAVIOR DEFINITELY BETTER, e.g. DOUBLE, FREQUENT IN ALL SOIL f(CPT) e.g. E $\approx$ (2-3) CPT
14- k	EASILY ESTIMATED FROM GRAINSIZE AND POROSIMETRY, e.g. k $100D_{10}^2$ AND MANY MORE RECENT CORRELATIONS, ROUGHLY SIMILAR
15- Ko	IMPORTANT TO ESTIMATE JOINTLY WITH (5), (6), (7), (8), (9). IN CLAYS 10 $\lesssim$ PI $\lesssim$ 100 e.g. Ko $\approx$ 0,0049PI + 0,44. FOR UNIFORM SANDS POSSIBLY FOR GENERAL SOILS?

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