

Opening renewed and continually renewing vistas for geotechnique through widespread diffusion of simplest Statistics-Probabilities (SP) with nominal Confidence Intervals, (CI).

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Abstract

One cannot fail to note that whilst most other technologies, both ultra-macro and mini-nano, have progressed exponentially, civil-geotechnical engineering has rested its early laurels of well-intentioned and courageously free intuitions, and fallen into a sterile abundance of inconsequential submissions of case histories in the dead languages and indices of yore. Advances and admonitions occur in parallel, but deprived of renewing syntheses. Dominated by prescriptions and codes, the unperceived cost is high in suppressing the inexorable percentage of HAZARDS and RISKS through disregard of 2 of the 3-legged supports of our greatest artisan of the QUALITY-OF-LIFE, technical, economic, and logistic. As has been said we have the greatest respect and affection for the PAST, because that's what has brought us hither, but our interest is in the FUTURE, because that's where we are going to live the rest of our lives. We cannot condone continuing the trek under the complexes of determinism, certainty, and "everything is known", under rigid mathematical idealizations, whereupon untouchable, and surviving through unperceived excessive costs. Life develops through its complexities under permanently inviting transient gerundives which are posited and exemplified, in substitution of DISCIPLINES. Geotechnique as an art applied to a natural science is primordially complex and singular, unless and until proved reasonably analogous to other cases in first-order parameters, progressively extendable by more intervening parameters and not by extending mathematical probability equations to remote tail ends.

1. Posits summarizing an extensive and intensive reference study.

- 1.1. It is strange to begin by explaining, in expatiation and apology that the terminology "nominal Confidence Interval" is being used inappropriately in the face of pure Statistics and Probabilities, and even the retreat to a designation "Nominal Reliability Probabilities" would require apologetic justification. One begs forgiveness for the need to emphasize that personally (and in fact in honest expression of all of Civil-Geotechnical Engineering) one's profession is dedicated to Reliability, in terms of recurrence Probabilities, in order to update from DETERMINISM¹ coupled with the antipode of "ACTS OF GOD". But as a first step, primary school, it is we (the teachers on geotechnique, more knowledgeable) that have to begin by speaking in the language of the children, our "should-be class to be seduced", and not the opposite, notwithstanding how more correct.
- 1.2. There is unanimous recognition that performance predictability in geotechnical practice is very poor, involving multiple co-persisting distinct models, prescriptions and pseudo-correlations, mostly resorting to single parameters intuitively and audaciously offered by erstwhile mentors.

¹ One must not delay in submitting that there are also truly deterministic cause-effect conditions. A case of a deep piedmontic alluvial deposit in a wide valley, which became the foundation of a very important dam appeared convincingly deterministic (De Mello 1981). Fast flood flows brought big boulders up to metric diameters, and the dominant gravels-sands were identified as gap-graded materials. The geomorphology would suggest that the high velocities required meanders for energy dissipation, and the boulders were moved and deposited along such curves: they became the "breakvelocity" facings protecting depositions of contiguous sands, just behind, in the calm-backwaters. The combination, most unfavourable, was not probabilistic, and resulted serious.

- 1.3. Physically patent periodic unfavorable performances derive mostly from human errors. However, undesirable model errors abound throughout, understandably from prudence imposed by primordial ignorances. The resulting overcosts, unperceivable to society because never exposed, accumulate into greater loss than accidents, or much worse, into compounding both losses.
- 1.4. Among such errors we posit the need to distinguish between cases that are dominated as pertaining to the “Statistics of Extreme Values” as opposed to the “Statistics of Averages”. The present presentation will not broach the cases of the first type. Facing the obligation of computing, and of “Reliability” (presumably “absolute”) the dominant trend has been to develop idealized probability formulae leading to extremely high values for the critical “disturbing action” under query. Our own emphasis, ever more strongly and justifiably espoused, has been towards an optimized composite of the two weapons: on the one hand, using the really high numerical procedures applicable, but, on the other hand concomitantly employing the only protection of humility from the inscrutable “Acts of God”, by “changing the project’s physical statistical universe” so as to obviate quite definitely the incidence of the catastrophic behaviors, impossible to be confirmedly encompassed by the mathematical extrapolation (De Mello 1977).
- 1.5. Within the restricted scope of conditions of Statistics of Averages, we seek optimized regressions and their approximate (comparative) nominal CONFIDENCE INTERVALS CIs either of single occasional point episodes, or of inescapably averaged behaviors, as dictated by the “physics” of each problem on hand. Reference is made to the “physics” because we inherited from Structural Engineering, and from industry’s advanced knowledge of Metals and Plasticity Theory, the emphasis on the physics of stress-deformation. The marked examples of other influences, such as, for instance, that of colloid chemistry, have not yet forced revisions: one notes such marked demonstrations as the efficacies of electrosmosis stabilization, or the strength loss and high sensitivity of lixiviated Scandinavian clays!
- 1.6. Conventional geotechnique developed around single parameter pseudo-correlations and prescriptions, with many parameters intuitively posited, others well studied but for idealized test conditions and the premise that real conditions should resemble those idealized except for negligible details. It is indispensable to revert and revise markedly, recognizing complex differentiations as the rule, and similarities as a conscious or subconscious concession.
- 1.7. In truth every single natural condition is different unless proved acceptably analogous. Hitherto prioritized parameters seldom achieve precisions and accuracies within ranges tighter than about 20-30%, i.e. CIs, of non-exceedance or non-defaulting less than 30 and 20% respectively.
- 1.8. Geotechnical works, if forced to abandon classical requirements of ZERO RISK, are required to respect at least extremely small hazards, e.g. 1:1000 etc... For a beginning one should adopt the nomenclature presently most widespread that HAZARDS reflect the probabilities of the event, while RISKS express the compounded probabilities of the destructive consequences of the given HAZARD; and we are to guard principally against the least frequent catastrophic RISKS. Simple optimized regression equations would suggest the best solution, but with important caveats, for widespread use, an absolute need in the face of countless complexities and erraticities, and optimizations between fewer more special studies and more numerous statistical samples of unselected approximate realities.
- 1.9. Unquestionably all of civil-geotechnical engineering aims at RELIABILITY, and not specifically ACCURACY. However, the first blatant anathemas to recognize and reject are the RELIABILITIES based on overdesigns, affecting starting buried overcosts and impaired logistics, all too rarely mentioned. The reliabilities of NON-DEFAULTING and NON-EXCEEDANCE on the three aims, technical, economic and logistic, calculable as referred to the composition of better accuracies together with CIs, have to be communicated to the intermediate (Project) and ultimate (Society) CLIENTS in the terms of common usage. These have nothing to do with the persistently promoted uncommunicative RELIABILITY INDEX, herein rejected.
- 1.10. Realities entice extrapolations, towards which life and the brain’s computers bless us with progressive sensorial perceptions, in total repudiation of sterile deterministic repetition. With each and every extrapolation into complementary and changing parameters, discovered, recognized and prioritized, that intervene or take

over dominance on the problem, the tasks become invitingly progressive. There is nothing more deterministic than an equation, even if it be a good Statistical-Probabilistic SP retrovisual regression, unless it be accompanied by CIs.

- 1.11.** The desired low risks coupled with progress can only be achieved by the multiplicative rule of Probabilities. Without much exertion one can find and confirm perceptibly proven parameters to incorporate, while keeping alert to differences. With 3 to 5 intervening parameters of the 25% dispersions, incorporated as intervening, the desired low risks of about 1:1000 can be reached through the multiplicative rule, for example, of about five intervening parameters of probabilities of 25%, 24%, 25%, 28% and 23%, as follows $(0.25)(0.24)(0.25)(0.28)(0.23) = 0.00097$. The engineering postulate stands that the learned refinements on the simplified inviting approach are less significant than Nature's erratic variabilities of parameters and idealizations in use.
- 1.12.** In gist, on putting together principally items 1.7 and 1.9, it is emphasized that while Extreme Value conditions must be set aside by changes of physical universe, 1.4, the acceptably low Risks and corresponding high Reliabilities must impose our realistically shunning tail ends of SP's postulated equations, and concentrating on COMPLEMENTARY PARAMETERS for each current single-parameter association, and subsequent humbling complex performance.

2. Comments on present status and minimal sample proposals of keynote purpose.

At first sight there would seem to be a shocking incongruity between the general impression given by the outstanding proportion of successful projects achieved, and of confident technical papers published on the one hand, and, on the other hand, of the occasional disparaging project failures and of the frustrating revelations from PREDICTION vs. PERFORMANCE CHALLENGES PPCs. Many obvious reasons may be listed, beginning with those characterizable as an inescapable "part of life". Our purpose is, however, to foster the factors that should better approach the realism of Nature's complexities and simultaneously offer a methodology for progressive improvement of reduced hazards with concomitant optimizations in all three components of engineering, technical, economic and logistic. It becomes indispensable to rekindle the courage of creativity regarding parameters and methodologies that have stayed unchanged, without known or adequate CIs, while the incomparably rich resources of computation absorbed almost every attention, or antiquated prudent CODES imposed significant overdesigns. Moreover, creativity implies discarding, as the ripening fruit must rot and fall for the seed to start new life.

The fact is that the vast but dispersive production accumulated with the best intents since the period of effervescent activity of reconstruction and construction of the post-war late 1940's calls for respectful and fond reevaluations and workshops for consensual corrections and simplifications in all quarters: these begin from names and designations, include indices and parameters erstwhile defined, and extend all the way to the most productive updated sectors, which have greatly bifurcated because of progressive verticalized specializations. The great and deepening rifts are obvious: firstly the separation between Academia and project field workers; secondly, within Academia, the rift between the exponentially multiplied facilities and speed provided by computation, and the efforts at updating equipments and tests; and above all the difficulties at reassessing hypotheses, mental models, and criteria (which are further greatly stifled by "practices", "precedents", "standards" and "codes"). Moreover, the greatest obstacle underlying all our works is doubtless the gradual difficult adjustments from the determinisms and ZERO-HAZARD/RISK of classical imposed concepts in comparison with the progressive transfer to our ultimate Clients, the Project and Society, of the concept of acceptance of tolerable or optimized levels of risk vs. the abandonment of the project. The computer has diverted a great proportion of attention from real-life field geotechnique, as paper accepts everything, and checking "proof positive" for mental models in simpler. When facing forefront equations of probabilities one rarely reflects on the questionable logic of using an equation, as one of the most deterministic tools of all, for tackling extrapolations on variabilities.

2.1. Beginning from the very question of concepts and terminology, the blatant examples come from the most critical Natural phenomena, ipso facto least subject to quantifications or confirmations.

For instance the phenomena that at a given (transient) stage of data and knowledge merited being qualified as “Acts of God”. The engineer’s needs of quantifications for problem solving have led to two alternative methods for such conditions, generally associated with Natural events of extremely complex causative factors, or extremely damaging feared consequences. The first tendency is to establish “by definition” some complex causative parameter and respective semi-quantifiable effect-parameter, in order to plot some graph of “boundaries” separating predictable possibilities and presumably “impossible prospects”. The subjective tendency is for overdesign, but depending on the need to be met, as demonstrably preferable to rejection of any action, the effort can merit mutual condonement, if honestly put forth in humility as representing the best possible estimated methodology and result, indispensable for use. In truth, there is never a real probability or credibility associated to the use of the terms “maximum probable flood” or “maximum credible earthquake”. Thereupon the application of a given (hopefully transient) STATE-OF-ART S.O.A procedure becomes a fair measure, especially for comparisons of project action vs. abandonment.

The yearly recurrence of maximum floods has led to the second alternate, comprising the postulation of different idealized mathematical equations for probabilities of recurrences of extremely rare events, such as the weakest link tensile failure of a chain. The purpose is, again, that of establishing an extremely high admissible flood peak, that might be called a “once-never” flood flow without impairment of the project’s feasibility. Regrettably the mathematical probability equation (obviously unheeded by Nature) permits a postulation of a 1 in 10000 year recurrence, which is really a preposterous extrapolation from data-bases that often cover no more than 50 to 150 years (and very frequently merit censure for not being either based on measurements during dangerous flood events, or systematically updated during the project’s life). Both the 1:10000 probability flood extrapolations, and the more updated sophisticated calculations of so-called “maximum probable floods” (with no probability attached thereto) call for censure as to the illusions conveyed.

2.2. Reconsidering in simple geotechnique the start-off problem of mere classifications by grainsizes as a sufficient example.

The case seems to be overdocumented, with references, persisting side-by-side, to nominal diameters of D_{10} , D_{15} , D_{50} , D_{60} and D_{85} . One shall not discuss the test procedures as divulged in all textbooks and crystallized (ever without firstly signifying the concepts incorporated) in test Standards by all countries. The adjective “nominal” is introduced because of the easy geometric recognition that the “diameters” represent the hypothetical spheres that did not pass through the square sieve openings, and the computed spheres that would settle under Stokes’ law. From the side of data-list we may list at least three first-order issues of lovable pure geotechnics that arise from the relative chaos; and from the side of useful results and design-construction conclusions, again we also can list at least three behaviors that have persisted running in parallel, and gradually dropping understanding in favour of “practices”, two of which are of great significance, involving failures (both extreme-value and average) while the third is of secondary consequence. The queries amplify when one faces critical natural phenomena, ipso facto increasingly variable and erratic, and also least subject to “proof positive” confirmations or quantification².

As a preamble one should recognize that (a) grainsize curves were the erstwhile parameter of soil classification, and any classification only arises with a view to favouring the forecasting of the significant behavior parameter. Historically the first hurdle and irrationality arose without delay. A blatant second-parameter distinction (b) between “clays” (pasty, sticky, slippery) and “sands” inhibited from the very start any attempt at classifying under probability equations. Moreover, the principal performance parameters may be summarized as strength, deformabilities and permeabilities (with their consequences, some of the “secondary ones” more important) : and it was obvious from the start that in all three, dominant influences are dependent equally or more on the pores (and their infillings) (De Mello 1993; 1999) than on the grain-structures that leave the pores.

² One emphasizes that the enormous advances in electron microscopy etc.. published very recently open new vistas. But that does not relieve one of the obligation of running some vectorized investigations on the enormous wealth of data to be retroactively analyzed by SP and CI.

Regarding both (a) and (b) one should note very briefly that in any field work in foundations, or borrow pits, or fills, one always deals with “families” of grainsize curves expressed by a band, analogous to that of CIs. One does not know any published (or any judicious) indication on how to handle such a routine problem of professional design or construction work. Typical tendencies in the face of distinct problems, average and secondary vs. extreme-value and serious, would be of using an average curve for permeabilities, and maximized severity for filters. One does not know of any statistical study, via some 20 tests, of the influence on variations of permeabilities (presently in terms of D_{10} or D_{15}) with plausible variations of respective $C_{U,S}$. The effects on filters, more serious, are broached in item 2.4.

A grainsize curve is really a cumulative probability distribution curve PDF, of the solids, erstwhile automatically taken as the dominant component for soil behaviors. However, because of Nature’s nature (as extensively recognized and used in medical and health problems, of very direct cause-effect responsibilities) the PDF should be very irregular (multiple-parameter regressions etc.), with different degrees of dominance of several parameters depending on the positions within the universe. It must be recalled that within a distribution curve of nominal diameter there are important correlated properties that generated, and accompany, the different fractiles: for instance, the coarse grains tend to be silica, can be angular or rounded, with consequent significant behavioural differences; the fines, finer silt and clay-fractiles may be flours of weaker minerals, correspondingly rounded, or clay-mineralogy colloids, and these with different adsorbed cations, also significant; and so on.

Let us summarize the points in an interpreted chronological sequence.

(a) Young sedimentary soils.

It is well established that the sequences of erosions, lengthy transport by water, and selective deposition under differing velocities, result in unitary particles (in mineralogical clays with their lysospheres fully developed). The quest was thus for the unitary particles. True to engineering principles of maximizations/minimizations the laboratory practices arose, including the erstwhile preliminary quest in series of test-tubes, of the most efficient deflocculant. Incidentally, some recognition of the influence of differentiated nucleations in clay-fraction soils, as completely disintegrated in standard sedimentation tests, was introduced in the Double Hydrometer Test and Dispersion Ratio for intended identification of Dispersive Clays, which merit a separate brief consideration in (c) below (Heizen and Arulanandan 1977).

One shall bypass the problems of angularities and crushabilities of grains, of conspicuous relevance to strengths and compressibilities. Incidentally, one has to practice at drawing side-information, depending on the nominal CIs : for instance much of the extensive research on “calcareous soils” can be relevant, by comparisons, for this important sub-classification distinction.

Attention must be focussed on the so-called “clay-fraction” (incidentally, reminding one of the damage frequently generated by the suppression of the word “fraction”). The problems of mass failures based on residual ϕ' s (term reserved for slow, drained, strain-controlled conditions) have drawn much attention over three decades. For a plane sliding surface, it could be an “extreme value” problem, but for curved surfaces one could accept it as pertaining to statistics of averages³. In short, slickensiding and residual ϕ' are fundamentally associated with laminar particles, “real clays”, and not the clay-fraction (< 2 micron). Why has it not occurred for some MSc or DSc thesis, of great use, to be run, in going back to the welter of published tests on residual ϕ' , to separate the proportions of rock-flour from the real clay, in order to improve on first-approximation knowledge by introduction of a second priority parameter? Updated techniques for such testing have been available for at least 15 – 20 years.

The simplest of problems, of young sediments have already been bifurcated. Quite a number of other intervening factors have been raised in publications, but apparently without the “proof positive”. For instance, the influence of ageing in the quaternary clays has been much emphasized, with relation to compressibilities and strength, and both using best-possible sampling and conventional tests. Some salient cases have even attributed the same age (e.g. roughly 4000 years) to the entire thick clay layer (when varved clays etc.. clearly confirm the obvious, that yearly

³ Incidentally such shocking catastrophic instant failures after prolonged shear deformations (such as the Vajont case) can only be visualized, in the senior author’s evaluation, not as a residual ϕ' case naturally asymptotic, but as transformed from the reduced ϕ' condition into a sudden stress-controlled high compressive Δu condition.

sedimentations are sub-millimetric). Several dating techniques have been in use in many other collateral uses, such as anthropology etc (of lesser consequence to humanity's quality-of-life), but one does not find convincing inroads into geotechnics. At the other extreme, under reasonable suspicions and quests, the microseismicity problems have introduced the G_0 crosshole tests since over 15 years ago. Has it occurred to check the variable effect with depth (and age) by such techniques ?

Further, for older sediments, there are the micro-cementations etc... that affect the resistances to such feared phenomena as piping, for which one recognizes that the "cohesion" and micro-strain strengths should be great allies. The same prevails, obviously to a greater degree, in residual and saprolitic soils. Considering the typically modest gradients of seepages, would it not be imperative to extend, both in the laboratories and in the field (foundations and compacted fills almost alike), such micro-strain (micro-stress gradient) behaviours in order to allay some of the reasonably adopted original maximized criteria that have represented such high increased costs in most dams ?

(b) Residual and saprolitic soils.

One uncontestable fact that was posited thirty years ago (De Mello 1972) is that residual and saprolitic soils derive from progressive disintegration (physical) and decomposition (chemical) "starting from rock" (hard to softer) while sediments arise from the aggregation of near-unitary particles (soft to harder). A few other posits of the time shall be added, but as a start, it is most irrational to apply the maximized intended disintegrating principles in order to conduct sieve-and-sedimentation grainsize curves for rational end-purpose classifications. The posit of that paper focussed merely as regarded foundations. But it must be strongly emphasized, from uncontestable field performance data on more than hundred-million cubic meters, that it also applies to compacted fills (with some variabilities dependent on the construction plant, excavation, dumping and lift-spreading, diking and watering, and compacting).

The fact is that these soils behave in terms of nucleations (of varied sizes), that have nothing to do with unitary-particle classifications. In foundation conditions, the starting physical disintegrations yield bigger nuclei (and coarser mineral grains when disintegrated) while the subsequent chemical decompositions (incident in greater proportions in tropical rainy regions, micro-laterizations etc..) lead to the smaller grain sizes, **but most often leaving the finer particles more accompanied by microcementations.**⁴ Thus the finer particles, considered more susceptible to erosions and ultimate piping (in view of the fact that essentially all tests on piping have been conducted on granular materials) are typically the ones benefited by significant complements of resistance by cohesions.

The first posit, regarding nucleations that survive in compacted fills, in sizes dependent on the plant, before any action from seepages, requires convinced and convincing affirmation, but is easily recognized in the field, and absorbed by reasoning. Earthmoving equipment has increased in capacities very greatly over the fifty years under focus: whatever the type of excavating equipment (scrapers, loaders, etc...) the fact is that it excavates "chunks" (of decimeters or more) and no matter what are the treatments on the fill platform, the compaction really corresponds to the pressing together of chunks of different sizes. Incidentally, as a side issue one must insist on the need to

⁴ One has already questioned the dichotomic origin of the global soil classification started-off from "sands" and "clays". [N.B. The tests and test results are not discussed herein, because of space restrictions, being accepted as deterministically valid.]. However, as a second issue one must mention that for young sedimentary clays themselves, the Plasticity Chart is significantly biased (De Mello 1993) because the Atterberg Limits are found to be too closely related, therefore failing to establish a really discriminating pair of coordinates. In short, the chart was better devised as a classification for what to avoid (e.g. for first-order bases of airfields) than for revealing better what and how to use. In the benefit of younger geotechnicians one excuses oneself in submitting two personal testimonies of those foregone decades and prophetic mentors. (1) Around 1965 Casagrande was given a contract by the Corps of Engineers to update the original chart by incorporating all possible complementary data. A considerable number of closely associated colleagues (the senior author among them) received the circular of data request. Regrettably the updating did not evolve, because of too much work, and as many exceptions as compatibilities. Often generalizations turn out easier when one has less data, on the single parameters intuitively chosen. (2) Without exception in all consulting work done in cooperation with such unquestionable figures as Terzaghi, Casagrande, Rutledge, etc..., the zealous geotechnicians who had prepared 30 to 50 cms (in height) of basic test data, were frustrated by the blunt declaration "I don't look at all that. Let me go and see and feel the soil in situ for myself". A posture less validating of the identification/classification tests/inferences than one would hope and teach.

investigate the physical conditions of undisturbed block samples of the borrow pit, because much of the performance is dictated by the “surviving” nucleations. Many of these surprising revelations occurred at the Tres Marias and the Paranoa Dams (De Mello 1975) as very briefly summarized regarding the lesser field permeability of the more silty shoulder in Tres Marias, the differences in different field permeability tests (much more impervious with augered wall smoothed by the cylindrical bucket-auger vs. roughened walls, which matched laboratory block samples, much more pervious, with dyed preferential paths of the contacts between nucleations), and also by the excellent resistance to intense rainfall erosions of the steep 1:1 slopes in Paranoa, because of absorptions by the big chunks. In the subsequent 40 years the principles behind these observations of subjective experience were systematically confirmed, justifiably, to different degrees case by case. No confirmatory research testing ensued.

In short it is a gross aberration to use minutely destructive tests for the classifications of soils, such as tropical residuals, saprolites, and laterites, which are dictated dominantly by in situ undisturbed performances. It is not easy to develop a meaningful classification as desired: but it is easy to drop entirely the totally-destructive testing, and to “play creatively” with different hypotheses of semi-destructive tests (such as partial disintegrations by different jets of different fluids, and many others, such as a greatly softened type of Los Angeles test for dry conditions, etc...). The fact is that the irrelevance mentioned has been tiringly repeated: and by composing several (not merely two, and badly chosen as one discovers to apply even to young sediments) significant intervening parameters one should progressively advance the meaningful bands and limits of effective relations between index and fundamental parameters, and on to complex project performances.

In emphatic comment, classifications that arise and restrict themselves to fully destructive tests (both on “sands” and on “clays”) are a gross aberration when in situ conditions, including void ratios and cohesions (as a mere start), etc. provide collateral dominant (if not priority) parameters.

Before returning to the simple case merely of grainsizes, attributed pointed and singular significance to such a serious problem as “piping” in dams, may one query what investigation has been conducted on seepage erosive stresses, and consequences, on in-situ-materials with cohesions? Before the need arises to filter base materials, there has to be the erosive origin of the malady. It is a serious prior consideration to much of the crude disoriented testing done for Dispersive Clays and consequent filters, and one has to resort to appropriate references, such as Partheniades 1965. In professional practice one has found far too frequently that the first (and sometimes even second) filter-transition material is patently very much more erosive than the base material presumed to need protection parameters, and updated uses of nominal CIs on multiple-regressions, and/or the multiplicative rules of composite probabilities, the roads to the clear end-purpose must be sought, recognized, tested, and posited with the same audacities as were shown by the early mentors in the 1920’s. Incidentally, one shall not extend into the further posit of the principles of natural selection, and of the greater responsibility shouldered by more efficacious participant (De Mello 1972) in soil each mass.

c) Dispersive Clays.

It is not one’s intent to delve into this problem which merits a separate consideration because on the one hand it laudably incorporates the principle advocated of introducing complementary tests and parameters, for improving the engineering reliabilities, on the other hand the tests created are devoid of any oriented reflection on the intrinsic factors and parameters at play. Attention to the piping failures in earth dams (N.B. as stated, without filter-drainage provisions) was called by the Australians, Aitchison and others, 1960, 1963, 1965 (Aitchison 1960; Aitchison et al. 1963; Aitchison and Wood 1965). In a special Symposium, ASTM STP 623, 1976, on “Dispersive Clays, related piping, and erosion in geotechnical projects”, Mitchell, J.K. and co-workers (Moriwaki and Mitchell 1977; Statton and Mitchell 1977) properly broached the subject as connected with colloid-chemical effects on the soil by seeping chemically affected waters from the reservoir.

Special reference must thereupon be made to the paper by Heinzen, R.T. and Arulanandan, K, in the same symposium (Heinzen and Arulanandan 1977) because they list the three principal test methods developed, called “qualitative” by the authors, in which on the one hand the main posited action is not given the due priority (if not exclusivity as a start) and the net result is that significantly different graphs are obtained, and the intended differentiations between danger of dispersive piping, or safety thereof, are merely established by rough boundaries, often contradictory (under the inevitably limited test conditions employed). The three tests are the

- (1) Double hydrometer test (resulting in a Dispersion Ratio) but using as references (a) the mechanical agitation⁵ and a (single) chemical dispersant of the “standard hydrometer analysis”, and (b) without mechanical agitation and with distilled water ;
- (2) crumb test consisting of “dropping a small, moist (natural moisture) clod into a clear beaker of distilled water or 0.001 nominal sodium hydroxide or both” and watching for a colloidal cloud to develop around the periphery of the clod”.
- (3) Pinhole test, an erosion test for water flowing through a hole punched in the specimen, results obtained by a measure of the cloudiness (turbidities in Jackson turbidity units, JTU).

It can be seen that none of the three tests are really oriented towards the priority problem posited, of cation-exchange reactions causable by reservoir seepages of chemically contaminated water, and leading to flocculations and accompanying greatly increased erodibilities. Moreover, the tests were loosely specified. But a phantom of mythological nature was raised to add to the rightly feared extreme-value-statistics problem of piping, and dam failure. Thousands of tests ensued, and in many cases, numbers of added filter-drainage layers were added, at great expense, and even some incremental risk⁶.

2.3. In valid grainsize curves of young sedimentary soils, distilling by judicious discarding the excessive accumulated defined fractiles, D_x .

Priority consideration must obviously be given to problems leading to failure, especially if dictated by start-off point behaviours capable of degenerating, and therefore pertaining to extreme value probabilities. Two performances are persistently considered deducible from the grain sizes (duly minimized to unit particles): filter protections against piping, and permeabilities. The latter, pertaining to statistics of averages on both component steps (including flownets) thus lose precedence.

Permeabilities assumed historic precedence as correlatable to the D_{10} (Hazen 1911, cf. Taylor 1949, p. 112). In comparison with the greater importance of the D_{15} (because of filter criteria) one concludes that in any moderately continuous curve a very simple transformation of the coefficient should permit abolishing the D_{10} in favour of the D_{15} . For instance it is shown that $100 D_{10}^2$ cm corresponds to $35 D_{15}^2$ (Sherard et al. 1984(a)).

It was hoped that the existent, widely divulged and respectfully taught and used relations and data-bases, should be available for reasonably useful SP analyses complementing the past. The hope was dismally frustrated, for the very reason of the religious erstwhile beliefs in single dominant parameters, prophetically posited. At this point it is important to recognize that one pays a penalty because of the decision to reduce hazards by increasing complementary parameters, because as a rule typical earlier research failed to measure side parameters as dispensable for being merely under suspicion of possible perceptible influence. One must resort to mental models and suggestions for future tests. Thereupon, the present effort merely advances somewhat under schematic indications for pinpointing the wide gaps of pure geotechnics demanding vectorized research and less chaotic licentious definitions of parameters as if irresponsibly isolated.

One criticism to the D_{10} , very often not reached in present-day grainsize curves of base soils (and not much relieved by a shift to D_{15}) is connected with the “discontinuous curves” frequently met in medium to coarse sands and designated as pertaining to “double sedimentation”. Percentage clays up to about 20-30% can infiltrate as “dirty waters” persisting during slow flows in sand structures already established in faster or sudden deposition: they are thus inconsequential, washing in and out (De Mello 1975). Without any incursion into further dominant factors in the

⁵ Note, however, for instance, that ASTM Standards (e.g. 1978) permit separations either on the # 200 (75 μm) or #4 (425 μm) sieves (requiring due mention of the case opted) and report great preference for air-dispersion. It reaffirms the obligation of SP handling of data and inferences, since not even REFERENCE STANDARDS are respected, in routine work.

⁶ It may be noted that since most filter tests and consequent criteria, prevailed with relatively uniform grainsize sands, it was not uncommon for the first layer to be of fine sand, much more erodible.

below- D_{20} clay⁷, it is instructive to summarize the wide distinctions and differentiating influential parameters divulged by the historic text book by Taylor (1948) (pgs. 115, Fig. 6.8 and 116, Fig. 6.9). The great and seemingly abrupt differences (because limited to two representative sedimentary soils) surely merit being investigated regarding the intermediate continuity (and relationships for inter-and extrapolations). One notes that for both soils the range of void ratios is identical, between 0.6 and 0.9, for which one may focus on the influence of the median 0.75 and the range 0.3. The historically expected meaningful parameters were established, D_{10} and $C_U = D_{60}/D_{10}$. We know that one would aim merely at permeability formulations, of secondary relevance in comparison with piping. Upon comparative analysis one notes the very great difference arising from a differentiation attributable to the porosimetry: and methods for determination of porosimetry (at least surely of the continuous type) such as the mercury-intrusion one have been divulged over about 30 years, with no perceptible inroads into geotechnique. Imagining a reference research on a subject like this that has long since been left by the wayside, is like looking for a needle in a haystack, in comparison with “fabricating” some purposeful differentiated porosimetries: compressibility involves all macropores, continuous and isolated, whereas permeability involves only the first⁸. We know that there are thousands more pores in the finer material, adding up to the same void ratio, and in the extended grainsize much greater variability of pore diameters, but there are also thousands more “grain” contacts reducing “intergranular contact stresses” (as extensively investigated and published by Marsal and co-workers, UNAM, Mexico, and briefly introduced indirectly in one’s Rankine Lecture (De Mello 1977)). It seems incongruent that the same global pore compression ($\Delta\varepsilon$) should produce so much bigger than expected a change of pore sizes effectively available to permeability. One has to start with some mental model. If one merely goes back to old data one mostly finds data missing for minimal analyses of trends, leave alone for SP and CI formulations. Armed with a mental model, e.g. of different consequences of continuous vs. isolated macropores, present laboratory techniques indicate the efficacy of vectorized testing, for instance by creating continuous vs. isolated macropores by insertions or dissolutions, etc. At any rate, one can and should eliminate one of the two, the D_{50} (mentioned regarding filter criteria) or the D_{60} , since their closeness in the middle-region permits easier transformation than was the case with D_{10} and D_{15} . In comparison with so many neglected or haphazardly used factors any error should be secondary.

Let us use the designations SU for the uniform sand, and CSE for the clayey sand of extended grainsize ($C_U \approx 56$) soil. By the Hazen correlation (used beyond intended limits) since the D_{10} are about 100 times, the permeabilities SU/CSE should be about 10 000 times higher (comparing at the median $\varepsilon = 0.75$): they result about 4 300 times higher only. This would seem contradictory to the expected consequences of more clayey participations and more varied porosimetry. The proportional changes due to global compressions between $\varepsilon = 0.9$ and 0.6 are of reducing permeabilities to 36% in SU and to 0.5% in CSE, a much greater consequence of porosimetry compression in the finer base soil: a significant disproportion, and apparently contradictory to the physical hypotheses regarding eventual macropores. One refers to these data, more than 50 years old because of the well-intended theoretical formulations on “seepage through capillaries” resorting to Reynolds, Poiseuille, Kozeny, etc summarized as first-order offered theoretical bases, and because of the meritorious and merited influence exerted by Taylor’s textbook. The time is more than ripe for recognizing and investigating the magnitudes of the interferences of complementary parameters.

In conclusions, besides the fact that filters are much more nevralgic than permeabilities, and all permeability indications using D_{10} are directly transformable to relations on D_{15} , one should not hesitate to discard both the fractiles D_{10} and D_{60} (for C_U). The D_{10} as already discussed and the D_{50} because it is easily relatable to the D_{60} on which one has the vast majority of mid-region particle size data because of the C_U . The periodic need (easily noticeable) for such a mid-region characterization occurs for checking on cases of foundation materials with extreme gap-gradings, as posited in Footnote 1, pg. 1 above, and exemplified in Fig. 3 below.

One should pursue, however, fully recognizing (1) the need to investigate the base material erodibilities in varied materials (2) the complementary parameters of ε and $\Delta\varepsilon$ of significant (noted) effects (3) reexamine all tests and

⁷ Such as the three major distinctions between “sandy-clays” vs. “clayey-sands” based on the differentiated dominant component, affected by distinct fractiles and mineralogies and composite physical indices, depending on the fundamental parameter sought, compressibility, strength, permeability, etc...; and further, the subdivision of clay-fraction into mineral flours and clay-minerals; etc...

⁸ One immediately imagines the finer material as a hypothetical “base” for filter research, with the second as a typical (too) uniform filter. Why has the research on the base behaviour, preceding the need of filters, been so dismally neglected?

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conclusions on filter criteria severely, without indulgence, regarding absence of attentions to such, and similar, physical and chemical influences. Preference centers on the D_{15} and D_{85} fractiles of really effective PDFs of nucleations or near-unitary particles⁹. It is surprising to reexamine old tests using updated orientations, and to reach the conclusion of how much correction and complementation is really required, whilst they enjoyed permitted survival by overdesign and overcosts.

2.4. Minimal comments, intended of constructive criticisms, on FILTER CRITERIA, on the basis of most prevalent present data.

So many, so arbitrary, and so incompletely documented have been the mental models and tests generating filter criteria, a serious matter involving dismal or catastrophic failures to DS, that it is convenient to start by discarding.

(a) Probabilistic approaches based on idealized packings of idealized spheres, and computed pore sizes.

Although the initiative arose, and progressed, under the intelligent enthusiasm of one of the senior Author's students, and successors (Silveira 1965; Nogueira 1975; Wittmann 1979; and others) it is rejected as essentially impossible to cover the porosimetries of though-flow pores of widely varied and varying soils. At any rate independently of filtering or not (a problem doubly composite) the first step should be to check the presumed probabilistic continuous pores with mercury-intrusion tests and other techniques of chemically inverting the grains and pores (cf. Sherard et al. 1984(a) relatively unsuccessful attempt by using molten wax). The principal interests aim at minimizing successive near-uniform filters by use of continuous (non gap-graded) extended grainsize distribution that (1) do not achieve packings so dense as to risk resulting insufficiently pervious, i.e. draining (2) do not possess small cobbles, rounded and rolling, that lead to segregations on lift-spreading, both to sides and to front, one of the least investigated topics, but responsible for many serious failures. It makes the fractile above D_{85} more important when it fans out to the right.

Some queries on the first two publications were included in De Mello 1977.

(b) Definition on the basis of permeability.

A single example is known, but of significant importance by its paternity (Vaughan and Soares 1982). One's reflection is contrary on the basis of principles. Firstly there is the big probabilistic difference between the reliability of permeabilities determined on specimens and the local erraticities unavoidable in the field. Moreover, the job's behavioural principles are diametrically opposed: on the one hand the behaviour of seepage permeabilities involves two steps of statistics of averages and medians, Darcy's k cm/sec, and Laplace's definition of the flownet; on the other hand the piping phenomenon belongs to the statistics of extremes of a "point" at the DS end suffering erosion, and thereupon a fair probability of progressive retro-degeneration by continuous shortening of the seepage length over which to distribute the gradient under fixed head. Favourable interventions, sometimes observed, depend on the soil not being able to sustain the "tunnel" with the respective applicable "stand-up time".

(c) The posit of erodibility, and critical erodibility shear stress of free flow along a crack.

One is not considering here the back-analyses of badly designed-constructed dams. The interest focusses on bases for reasonable future designs, despite confusions, deficiencies, excesses and errors. One broaches herein merely one well sired publication, Arulanandan, K. & Perry, E.B., 1983. There is a promising avenue indicated for many a collateral condition. But one has to distinguish between tensile cracks that stay open, and shear cracks that don't open and frequently become more impervious. And tensile cracks belong to cohesive materials and the upper part of the dam, assuming the eventuality that they are not avoided altogether. What seems very difficult to accept is (1) tensile cracks deeper down and (2) above all, the posit of "crack potential of the filter", generally cohesionless.

⁹ One notes that in latter days Sherard (Sherard et al. 1984(a)) called for sedimentation grain sizes with and without deflocculants (without expatiations on the reasoning).

(d) Recanting on the dominant importance personally attached to the welter of tests by Sherard et al. 1984(a), (b), two papers, ASCE, GT 110, 6, 684-700, and 701-718.

In his partial contribution to the Special Lecture C: “Embankment dams and dam foundations” XIIth ICSMFE, (Vardé, O.A. et al., 1989, especially 2180-2200) attentions were excessively concentrated on analysing the probabilities of adequate performance of a considerable series of tests of the then apparently most recent extensive publications (Sherard et. al. 1984 (a), (b)) on (a) idealized “sand and gravel filters” and (b) “filters for silts and clays” including both “non dispersive and dispersive clays having similar particle size distributions”. In both cases one should raise significant queries, very summarily posited as follows:

(1) The base soils were extremely uniform. As usual, the physical indices of porosities of the filters were loosely subdivided into “dense” and “loose” state, and further characterized by median, and range, of permeabilities, which has already been explained to be too indirect a parameter, especially in the field, where, moreover, inspection testing concentrates on physical indices. Other queries further indicate some questionable orientation of the program; the principal query concerns the facts that the tests applied “rapidly” compressive gradients of the order of $400 < i < 800$. Assuming that in most embankment dams compressive gradients are of secondary concern in comparison with tensile ones, and gradients are mostly of the orders of $0.2 < i < 1$, even with a factor of safety of 10 or 20 for localized conditions, one cannot understand the excessively high ones used. Another point of design significance is that the tested filters were also extremely uniform $1.5 \leq UC \leq 6$ pointing towards eventual need of successive layers for transitioning as the only solution, whereas in practice it is often found convenient or preferable to use more extended well-graded granular materials.

The worst condition imaginable corresponds to the hypothesis of cobbles (as outliers) not pertaining to the well-graded base, or filter, grainsize of much more extended inclined grainsize distribution. Outlier gravels bigger than the lift thickness (e.g. 25 cm) are automatically removed¹⁰ but one still has to consider the implications of some percentage (e.g. $\leq 30\%$ ¹¹ as much quoted) of fractiles much bigger than those corresponding to the C_U of 6 starting from the upper limit of the D_{15} criterion. One refrains from mentioning the great proportion of dams on which extensive hand labour is used to pick-out such cobbles: the interest, considerable, lies in using the benefits of continuous well-graded flatter-lying grainsize curves, for minimizing the successions of uniform filters. Assuming the good continuous grading there is no effect on internal erosions, only a change of effective permeabilities. The $\leq 30\%$ experience is claimed for before the cobbles¹² create intergranular contact structures with big pores.

For the maximum effect (30% cobbles) on permeabilities, the sequential geometric computation is direct, assuming a dry unit weight for the soil mass and specific gravity for the cobble: one limits to the striction caused at mid-section of spherical cobbles. For instance, using 2.7 and 1.7 t/m³: the 30% of total weight yields 19% of total volume. Calculations have to be based on the solid sphere, impervious and incompressible, and the porous matrix of interest has to follow by differences. The ratio of area to volume of $3/4r$, coupled with the ratio of volumes, of sphere to cubical volume x^3 , lead to an $r/x \approx 3.58 \times 10^{-1}$, and consequent area ratio $(r/x)^2 \approx 12.8 \times 10^{-2}$, i.e. 12.8%. Thus the volume compressibility is reduced by 19% (favourable) and the permeability by 12.8% at the minimum section.

In the base (core) material it is but modestly beneficial. If the filter is satisfactorily designed, to increase permeabilities of the order of 20 to 25 times, the decrease of drainability is also inconsequential.

The serious problem, very poorly researched lies in the succession of segregation and agglomeration dependent on field construction plant and practice.

¹⁰ Presuming as a priority fundamental their not being pushed by segregations to clusters and linear US-DS accumulations.

¹¹ The research tests on these subjects need great amplification for coverage of typical conditions. Such limits, persisting on deterministic boundaries constitute the source of many sinkhole failures. Moreover, although the principal effect is on permeabilities (i.e. also filter drainabilities) considered secondary, the correlations such as $k \approx 35D_{15}^2$ merely with the finer grains, without incorporating the great influence of high C_U on imperviousness, also needs serious complementary research.

¹² One notes that the USBR 1974 criteria limit cobble sizes to passing a 3-inch sieve, too severe, unnecessarily, as regards individual particles, not clusters.

(2) The tests were openly declared to have been aimed at checking the “critical” filters needed to seal concentrated leaks, both of water and of “slurries”. Gradients used were $1000 \leq 2000$, and these were applied “abruptly”. As understandable, under the implicit hypotheses of a crack with flowing slurry, the physical indices of the “base” soils are irrelevant, but should be of some influence for the filters.

In summary, it appears that the aim was to demonstrate that the Terzaghi-Bertram confirmed being satisfactory for almost all tests, even under the extreme conditions imposed. Reference to the Discussions (ASCE, GT, 111, 12, pp. 1467-1472) is withheld because they concerned the US Bureau of Reclamation filter criteria which constitute the next-but-one item, of the chosen posits to summarize the question of grainsize distribution characterizations for the important subject of filter-drains for dam safety.

(e) Brief considerations on clayey soils. Separate caveats for saprolites and for sedimentary clays.

In principle the soil behaviours, as per classical identification and classification tests, cease to be controlled by grain sizes, being superseded by the Atterberg Limits. One has already pointed above to only one of the secondary problems, such as the alternates for determining laboratory grainsize distribution curves. Thereupon follow the queries raised on nucleations, true clay-mineralogies, etc (cf. Footnote 5, pg. 8). The same Reference, 1978, fixes for the Liquid Limit the fractile passing the # 40 (425 μm) sieve, but limits also to the questionable collateral standard of “dry preparation of soil samples for particle-size analysis and determination of soil constants”¹³. And so on. The loopholes left for designer decisions are too many, but will not be extended.

Terzaghi’s intuition had since the beginning recognized that the existing near mid-point definition of the D_{60} by the C_U , left too wide a range for unfavourable interferences of cobbles. The case of four typical archaen granitogneisses is used, in part for collateral comments¹⁴. Even limiting to the use of single-line (averages within broad bands) for each saprolite (as per De Mello 1975 and Da Fonseca, et al. 1994), and considering only the least clayey, that from OPORTO, Portugal, and using continuation of the very narrow band of non-uniformities of the order of $1.5 \leq C_U \leq 3$, the mere displacement of the arbitrarily fixed single start-off points upwards from D_{60} (Fig. 1A) to the D_{85} (Fig. 1B) reduces the top band to about one-half.

In gist, the intuitive concept of limiting the “near-extremes” (such as D_{15} and D_{85}) is imperative, though extremely insufficient, for different reasons at each extreme, and clamouring for complementary effective parameters. At the upper extreme, the “near-outliers” and segregations and non-adherence of chunks; at the lower extreme as already noted, because of nucleations, “non-activated” clay-minerals, inert rock flours, etc.

In the case of sedimentary clayey soils, one notes that geotechnically the fundamental control on micro-stresses and strains (e.g. from seepage gradients) are based on the cohesions, which are the first of the two nominal Mohr-Coulomb components (c' , ϕ') of resistance to be overcome. Cohesions, however, depend fundamentally on overconsolidations, either as partly remanent in the borrow pits, or/and as imparted by the compaction. There is no longer the concept of physical stereometric hindrance as in cohesionless soils. If the clay-mineralogy is truly activated, the finer the colloid the better tend to be the overconsolidated cohesions (unless allowed to swell), which emphasizes the design aim of using filter curtains oriented so as to cause compressive seepage flownets.

The final discussions on filter criteria have been relegated to item 2.4 below, and are found to limit themselves to grainsize curves and stereometric hindrance principles. Mention of the case of cohesive clayey materials is therefore summarized therein, because one finds it reasonably documented regarding types of behaviors. As usual, there is the blatant lack of collateral, complementary parameter definitions for the SP and CI reliabilities.

¹³ Have there been some series of tests researching on the effects of the excess coarser inerts on the Atterberg Limits?

¹⁴ The collateral comments are: Saprolites obviously begin by physical fragmentation since there has to be inflow of waters for the chemical decompositions. The coarser condition of OPORTO matches with lesser chemical action, much intenser in tropical, wet conditions of Brazil (N.B. One cannot glibly transfer “experience” from region to region). The saprolites only physically attacked disintegrate to steeper nominal grainsize distributions, which are, however, meaningless for internal erosions, because of residual micro-cementations. All saprolites yield extremely broad bands. The chemically weathered saprolites and residuals give flatter curves, most often not reaching either D_{15} or, even less, D_{10} . Some of the outcomes are exemplified in Figs. 2 and 3.

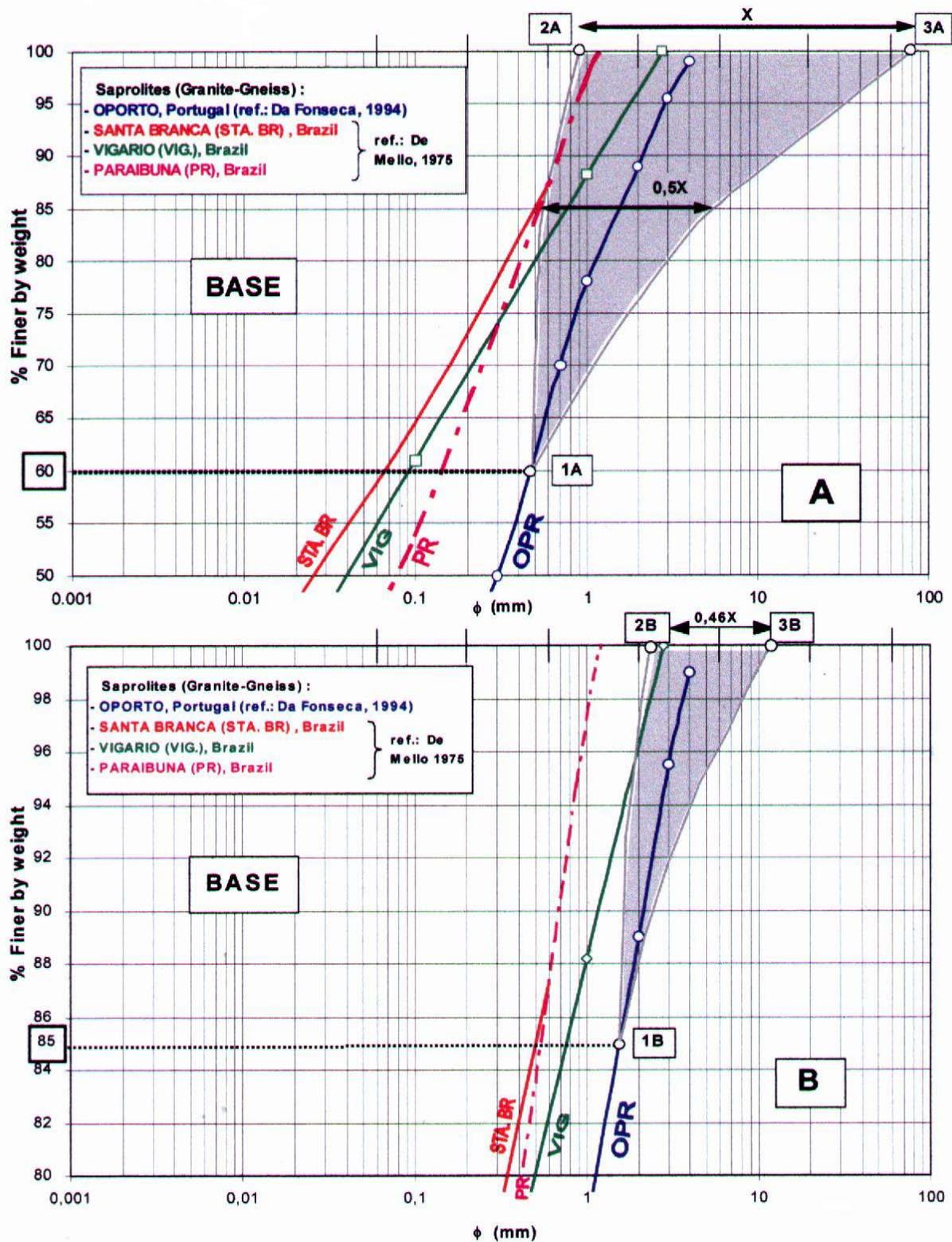


Fig. 1. Range of upper fractile much wider, obvious, with distribution based on D_{60} than on D_{85} .

2.5. Filter criteria as affecting variable design decisions on uniform vs. extended, and gap-graded vs. continuous grainsize curves.

Despite the importance of the subject one sees that attentions were drawn in different directions, corresponding realistic (with obvious judicious F values) confirmatory research testing was much neglected, and a significant latitude of design/construction decision/implementation is left to subjective “practices”. Thereupon one decides herein to concentrate on the three professional references of widest use, Terzaghi-Peck 1948, 1967, Terzaghi, K. et al. 1996, and the USBR Earth Manual, 1974. One employs once again the sequence by discarding.

(a) Active clayey materials, all caveats discarded.

It is indeed most surprising that none of these three basic professional references give consideration to such materials, although they should tend to be predominant in very many dam cores: in fact, extensive reference research leaves the impression that research tests did not focus on this case. One wonders if the researches and posits advanced in Europe and Israel (local needs obviously impose vectorized efforts) were “absorbed” as adequate, although if so, one would decry the lack of the indicated necessary complementary testing on the tensile and cohesive strengths of the clay near the filter interface¹⁵. An early reference, Davidenkoff 1955, of a paper to the High Dam group, may have affected the outcome. A theoretical basis was formulated and the seepage tests under high gradients were used proving that the failure started by ejection (resisted by tensile strength) of a semi-spherical chunk: obviously the follow-up should recall the importance of time, and swelling, for a clayey cavity affected by tensions and with free water seeping out.

The basic conclusion that persisted resulted, however, in the indication that due to cohesions and tensile strengths or cohesions¹⁶, much coarser grainsizes (even gravelly) could be satisfactory for adequate piping resistance. Other publications in the same or similar directions may be listed chronologically as: Kassif et al. 1965, Wolski 1965, and Zaslavsky and Kassif 1965, etc..., and including another paper of greater comparative influence because of submission to the High Dam colleagues, Wolski et al., 1970. One should emphasize further that the latter publication goes into the detail of formulating localized flownets and extreme exit gradient variabilities on the assumption of a crack up to near the filter interface, an item discussed in 2.4 (c) above.

(b) Principal composite behaviours to be considered in design/construction under typical field conditions.

Before finalizing with the gist of the prescriptions of Terzaghi-Peck 1948, 1967, Terzaghi et al. 1996, and US Bureau of Reclamation 1974, all concentrated only on grainsizes, and on adequate filter-draining of granular materials, it is imperative to note the other six factors of almost equivalent consequences. References to them are paltry.

Segregation and ulterior accumulations of segregated materials is a problem both of choice of materials and of judicious choice of construction plant and practices.

Treatment of families of representative test curves¹⁷. In any field condition with a few thousand tests one always faces a “family” with no less than about $\pm 15\%$ dispersions (of % fractile of diameter) around the median. Fig.2 submits the ranges of the filter D_{15} diameters to be used, depending on intuitive design decisions. (N.B. The subsequent corresponding Filter D_{85} diameters, for a possible successive filter depends on the additional design decision, which is what range of C_U values to accept). Civil engineering recommendations in the case of risks of catastrophic piping are to maximize safety, which would mean using, for a given family of base curves, the smallest diameter and diameter-range. The subject has never been researched and posited.

¹⁵ Unless the filter-curtain is placed in a trench excavated in the routinely well-compacted clay, there is always some difference of the interface clay, generally looser and more erratic. Construction logistics is important, and it generally places the separate materials side by side at each lift, before compacting.

¹⁶ A point briefly posited above in 2.4 (e).

¹⁷ One notes that in the most authoritative early reference, Terzaghi-Peck 1948 (pg. 50, Fig. 15) the subject of a family of base curves is shown schematically.

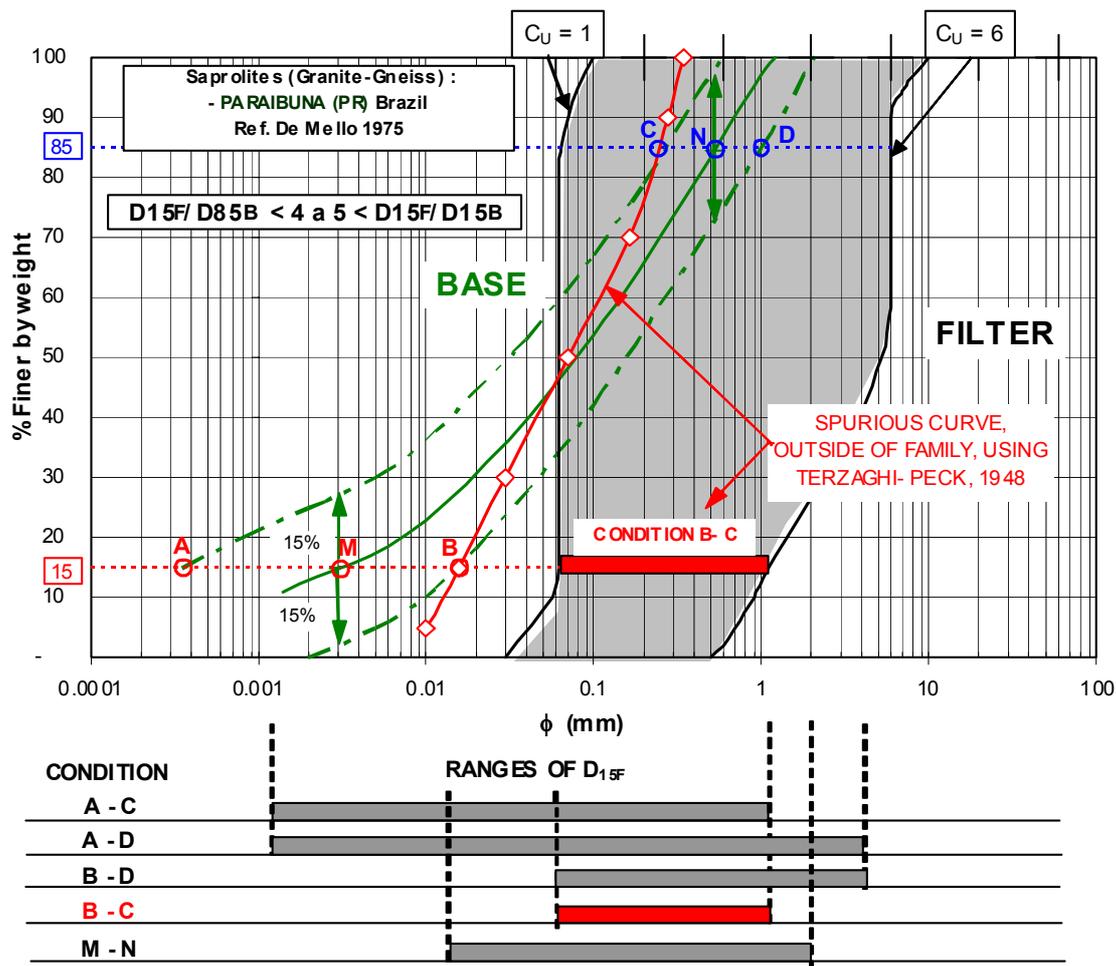


Fig. 2. Dilemmas on handling family of curves, and concept of maximizations/minimizations of civil eng'g.

Within the dispersion representing the family of base materials, AC, BD, and MN median there are three possibilities, of which the most used, by routine, would be the mean MN, and a prudent frequently used option is the AC. There have been cases, however, of extreme fear in which designers have used compositions of the D_{15} from one borderline curve, e.g. AC, coupled with the D_{85} from the opposite borderline curve, or vice versa. The corresponding ranges for the D_{15F} (filter), the only parameter really fixed under the reasonable posit that it is the fines that define probabilities of stereometric hindrance, are shown below the main figure.

It should be noted however that the use of mixed curves at opposite boundaries is far too arbitrary because it defines a hypothetical grainsize material not belonging to the family¹⁸.

Filtering and potential gap-grading. The parameter $CC = (D_{30})^2 / D_{10} \times D_{60}$, introducing yet another D_x fractile, was defined historically, but has been very rarely mentioned together with the conventional D_{10} and D_{60} data already discussed. It defines the hump or concavity of the stretch between D_{10} and D_{60} , of secondary interest. It is posited that values of CC below 1 lead to convex grainsize curves (humps) capable of inviting gap-grading, while CC values bigger than 1 are favourable, concave upward (and presumably favourable to $CC \leq 3$). As shown in Figs. 3, there is

¹⁸ With emphasis that in Terzaghi-Peck, 1948 (Fig. 15) the use of exactly this posit that one criticizes, is what is professionally suggested for application.

need of some mid-point to be fixed between the D_{15} and D_{85} , and it would appear of interest to use the D_{60} : this would require new research testing on an optimized COEFFICIENT for defining humps or concavities in the stretch of real significance, and respective values.

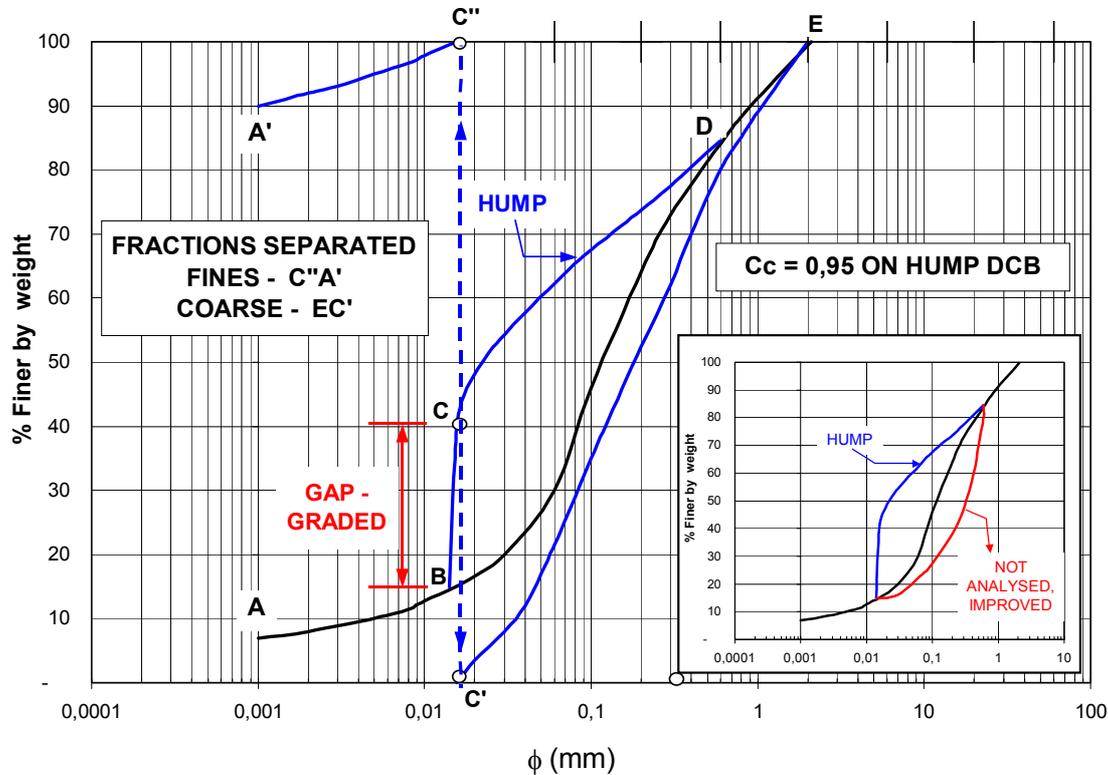


Fig. 3. Suggested method (De Mello 1975) of exposing gross gap-grading. Impossible internal filtering of fines by coarse fraction.

The place of serendipity cannot be despised in technological developments. The test proposed, De Mello 1975, for checking on gap-grading arose in 1953-'4 in a homogeneous compacted earth dam, 32 m, in a basalt region of flows interspersed by fine aeolic sandstones. The grading for the (vertical) filter curtain required mixing (N.B. also a problem to be controlled) of the fine yellow sand, and the black basalt crusher fines. Considerable testing was required, from which the principle was intuitively extracted: to subdivide the global distribution curve into successive parts, adjust each part to its transformed curve from 0% to 100%, and check if successive parts act as filters to each other. In principle it is assumed that since many thousands of particles are at play in each subdivided pseudo-soil, the procedure could be repeated, in the case of extended curves, for more than merely two subdivisions. Pressure of professional work did not permit really covering the research needs, not even for the subdivision into merely two parts visually distinct¹⁹.

Clogging of filters and subhorizontal filter-drains. The physical clogging by eroded particles has not been researched sufficiently, except through probabilistic reasonings. In tropical forested basins one has found that the erstwhile preference for the subhorizontal filter-drain to be excessively efficient, and thus dry, resulted unfavourable because of aerobic chemical reactions generating ferruginous concretioning: preference has shifted to maintaining the drain permanently submerged.

¹⁹ The prescription was presented at one's lecture in Berkeley, June 1971, as one of a series of lectures by a group of colleagues. As published, De Mello 1975, it has been accepted and divulged, but academically conducted research, with SP and CI should be required.

Opening of the recommended are upwards with the D_{15F} range fixed.

The most frequent recommendation centers around uniformity coefficients between 1.5 and 6 ($1.5 \leq C_U \leq 6$) in a vicious cycle, since the vast majority of tests were conducted within these limits or even tighter, 3 to 6. One wonders at the reasonings that might have led to such preference for “uniform filters”, which result in requiring successive filters, as shown in Fig. 4. Professional practice should obviously prefer more extended grainsizes (gap-grading avoided, as discussed below, cf. Fig. 3, requiring the fixing of some mid-point orientation). Incidentally, there are suggestions, unsupported by documentation mentioning the use of parallelism between filter and base curves.

One problem that occurs as one extends the curve, is that if it is well-graded, concave upwards, the material becomes more impervious, capable of reaching high clay-like imperviousness.

Early references to criteria, much debated, defined merely on the basis of the D_{50} s, base and filter.

Severe conceptual criticisms were fully justified, at some erstwhile prescription that was based on a median, when the problems were blatantly of the nature of maxima and minima. The lower end of the D_{15} filter band related to the base D_{15} , to guarantee smaller sizes and stereometric hindrance; the upper end of the same D_{15} filter band to guarantee drainability and exponential decreases of seepage gradients in the filter itself. On close scrutiny one notices that the tests had been run on materials almost perfectly uniform, $1.1 \leq C_U \leq 1.3$: thereupon with a single point defined, the entire curve, including D_{15} and D_{85} are obtained directly.

2.6. TERZAGHI-PECK 1948, TERZAGHI-PECK 1967, USBR 1974, and TERZAGHI-PECK-MESRI 1996.

Finally reference concentrates on these authoritative professional publications, as proof positive that much has been left incomplete.

(1) In 1948 they limit themselves to establishing the most basic, divulged rules, using the coefficient 4 (slightly more conservative than the coefficient 5 oft quoted as an upper range). Using F = Filter and B = Base:

$$D_{15F} / D_{15B} \leq 4 \text{ for stereometric hindrance}$$

$4 \leq D_{15F} / D_{85D}$ for adequate drainability. No further complications were visualized and broached; the schematic curves are continuous, and the filter area opens at the top within the $1.5 \leq C_U \leq 6$ of uniform filters.

(2) It is of interest to begin by referring to the end of the chronological cycle, inasfar as after examining publications as late as 1989, Terzaghi-Peck-Mesri return to the simple erstwhile schematic figure (Pg. 81, Fig. 14.14) and add another log-log plot of D_{15F} vs. D_{85B} (Fig. 14.15) and return to the 1948 criteria.

(3) Interest therefore centers on the US Bureau of Reclamation 1963 criteria, (of which one possesses the 1974 Ed.), because Terzaghi-Peck 1967 introduced addenda attributed to the USBR.

The following details are summarized:

(i) They refer to extremely uniform filters $3 \leq C_U \leq 4$

(ii) Thereupon they profit of a reasonable right to preserve the referencing to D_{50} sizes (otherwise queried)

$$\text{Uniform filter} \quad 5 \leq D_{50F} / D_{50B} \leq 10$$

$$\text{Graded filter} \quad 12 \leq D_{50F} / D_{50B} \leq 58 \text{ (rounded)}$$

$$\text{Introduced} \quad 9 \leq D_{50F} / D_{50B} \leq 30 \text{ (angular)}^{20}$$

²⁰ One fails to accompany any justifiable reasonings for such posits, and feels discouraged at pursuing investigations into the supporting tests, doubtless lacking complementing parameters.

WISELY COMPLEMENTED, reporting to D_{15S} , only the lower part of the curve.

$$6 \leq D_{15F} / D_{15B} \leq 18$$

One further notes the reasonable step of advancing towards some indication on the curvatures, although regrettably via the $C_c = (D_{30})^2 / D_{10} \times D_{60}$. (cf. Fig. 3).

The principal observation is that at least one (although not priority) complementing parameter, grain angularity, opens the door to one's repeated emphasis, for more parameters with SPs and CIs.

(4) Terzaghi-Peck 1967, Pg. 57, Table 11.2, reproduce the "Requirements for Filter Materials (after USBR 1963)", repeating exactly what is summarized above, and dispensing further comments.

It should not be found surprising that the most recent edition should have withdrawn from this USBR posit.

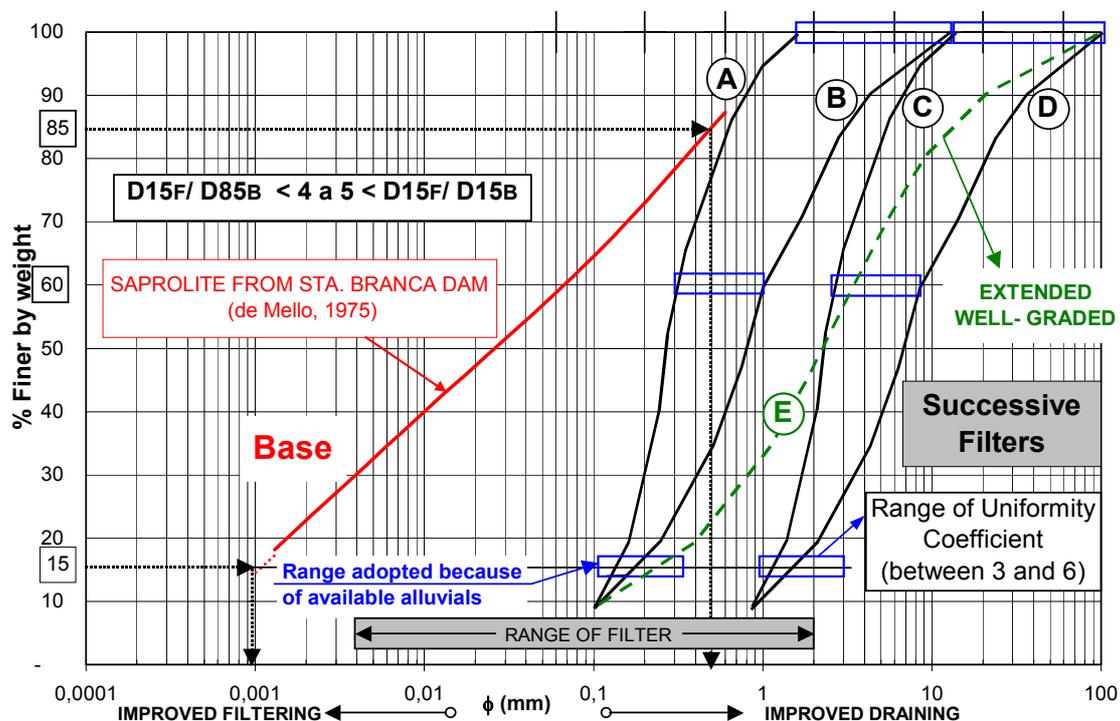


Fig. 4. Representative case of design/construction comparisons, successive uniform filters vs. extended well-graded gravelly-sand.

3. Concluding comments.

The propositions were, firstly, regarding the discarding of determinisms, and the reversal to simple SPs and nominal CIs for definitions of effective parameters, progressing from initial blatant priorities and consequent intuitions, and progressively incorporating complementary parameters. Secondly, that upon recognizing that in nature, in tests, and in the field, the non-exceedance and non-defaulting dispersions are seldom smaller than about 20%, in order to reach the tight levels of Reliabilities in most complex behaviours one has to muster three, four, or five complementary parameters affecting the given complex behaviour. Such a purpose is greatly accentuated in the face of failures tending towards catastrophic risks, when hazards are high.

Thereupon the simplest possible case was taken up, involving the filter criteria exclusively dictated by grain size curves and a vast array of fractiles, D_{10} , D_{15} , D_{30} , D_{50} , D_{60} , and D_{85} . Backanalyses of research tests regrettably are

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found deficient in influential side data, while over-documented, somewhat indiscriminately, with regard to different chosen fractiles D_x for first-order definitions and pseudo-correlations. Moreover, even the grainsize curves are far from representative for the behaviours of many soils. In separate, upon dealing with active clays, of likely participations in many a dam core, no mention is reserved for the cohesion, and its related tensile strength, both understandably involved in the start-off of piping. In short, one succumbs under the frustration of difficulties of even reconstituting complementing parameters in the academic origins.

Finally, emphasis has to be turned to the many factors that are dominantly influenced by job realities and construction plants and practices.

A subject that may have been granted safety either by chance or by overdesigns, the latter very expensive in many a regional condition, has been shown to be wide open to complementing research investigations, in series of 15 to 20 tests per group, in order to permit savings in technical, economic, and logistical factors, without any impairment of the reliabilities required by the Project Owner (client) and Society.

References

- AITCHISON, G.D. (1960) "Discussion on Cole and Lewis", Proc. 3rd Austr.-N. Zeal. CSMFE, p. 230.
- AITCHISON, G.D. et al. (1963) "Post-Construction Deflocculation as a Contributory Factor in the Failure of Earth Dams", Proc. 4th Austr.-N. Zeal. CSMFE, 275-279.
- AITCHISON, G.D., and WOOD, C.C. (1965) "Some Interactions of Compaction, Permeability, and Post-Construction Deflocculation Affecting the Probability of Piping Failure in Small Earth Dams", 6th ICSMFE, Montreal, 2, 442-446.
- ARULANANDAN, K., and PERRY, E.B. (1983). "Erosion in Relation to Filter Design criteria in Earth Dams", Journal of Geotechnical Engineering, ASCE, 109 (5), 682-698.
- ASTM, Amer. Soc. Test. Materials. (1978). ANNUAL BOOK OF ASTM STANDARDS, Part 19.
- DA FONSECA, A.V. et al. (1994). "Portuguese Experience on Geotechnical Characterization of Residual Soils from Granite", XIII ICSMFE, New Delhi, Vol. 1, 377-380.
- DAVIDENKOFF, R. (1955) "De la Composition des Filters Dans des Barrages en Terre", 5th ICOLD, Paris, Vol. 1, 385-401.
- DE MELLO, V.F.B. (1972). "Thoughts on Soil Engineering Applicable to Residual Soils", 3rd Southeast Asian Conf. on Soil Engineering, Hong-Kong, 5-34.
- DE MELLO, V.F.B. (1975). "Lessons from Unsuspected, Real and Fictitious Problems in Earth Dams in Brazil", 6th AFR. CSMFE, Durban, Vol. 2, 285-304.
- DE MELLO, V.F.B. (1977). "Reflections on Design Decisions of Practical Significance to Embankment Dams", Rankine, Géotechnique 27 (3), 279-355.
- DE MELLO, V.F.B. (1981). "Facing Old and New Challenges in Soil Engineering", Symp. Past, Present and Future of Geotechnical Engineering, M.I.T, Cambridge, 160-204.
- DE MELLO, V.F.B. (1993). "Revisiting Conventional Geotechnique After 70 Years", Anales de la Academia Nacional de Ciencias Exactas, Físicas y Naturales, Buenos Aires, Argentina, Tomo 45, 67-97.
- DE MELLO, V.F.B. (1999). "Geotechnical Engineering for Third Millennium: Seeking a Renewed Start", XI PCSMGE, Iguazu, Vol. 4, 119-157.
- HEINZEN, R.T., and ARULANANDAN, K. (1977). "Factors Influencing Dispersive Clays and Methods of Identification", ASTM, STP 623, 202-217.
- KASSIFF, G. et al. (1965). "Analysis of Filter Requirements for Compacted Clays", 6th ICSMFE, Montreal, Vol. 2, 495-499.
- MORIWAKI, Y., and MITCHELL, J.K. (1977). "The Role of Dispersion in the Slaking of Intact Clays", ASTM, STP 623, 287-302.
- NOGUEIRA, J.B., (1975). "On Void Distribution of Granular Materials", 5th PANAM CSMFE, Buenos Aires, Vol. 3, 160-167.
- PARTHENIADES, E. (1965) "Erosion and Deposition of Cohesive Sediments", J. Hydr. Div., ASCE, 91(1), 105-139.
- SHERARD, J.L. et al. (1972). "Piping in Earth Dams of Dispersive Clay", Spec. Conf. Performance of Earth and Earth-Supported Structures, ASCE, Vol. 1, Part 1, 589-626.

International e-Conference on Modern Trends in Foundation Eng. Geot. Challenges and Solutions. Jan. 2004, Indian Inst. of Technology, Madras. Site: www.ecfg.iitm.ac.in Themes of the Conf. / 13. General Issues / 13.1.

- SHERARD, J.L. (1979). "Sinkholes in Dams of Coarse Broadly Graded Soils", 13th ICOLD, New Delhi, Vol. 2, 25-35.
- SHERARD, J.L. et al. (1984) (a). "Basic Properties of Sand and Gravel Filters," Journal of Geotechnical Engineering, ASCE, 110 (6), 684-699.
- SHERARD, J.L. et al. (1984) (b). "Filters for Silts and Clays", Journal of Geotechnical Engineering, ASCE, 110 (6), 701-718.
- SILVEIRA, A. (1965). "An Analysis of the Problem of Washing Through in Protective Filters", 6th ICSMFE, Montreal, Vol. 2, 551-555.
- STATTON, C.T., and MITCHELL, J.K. (1977) "Influence of Eroding Solution Composition on Dispersive Behavior of a Compacted Clay Shale", ASTM, STP 623, 398-407.
- TAYLOR, D.W. (1948). "Fundamentals of Soil Mechanics", John Wiley & Sons, Inc., New York.
- TERZAGHI, K.V., PECK, R.B. (1948) "Soil Mechanics in Engineering Practice", 2nd Ed., John Wiley & Sons, Inc., New York, Revised, 1967.
- TERZAGHI, K.V., and PECK, R.B. (1967). "Soil Mechanics in Engineering Practice", 2nd Ed., John Wiley & Sons, Inc., New York.
- TERZAGHI, K.V. et al. (1996). "Soil Mechanics in Engineering Practice", 3rd Ed., John Wiley & Sons, Inc., New York.
- U.S. BUREAU OF RECLAMATION. (1974). EARTH MANUAL, 2nd Ed.
- VARDÉ, O.A. et al. (1989). "Special Lecture C: Embankment Dams and Dam Foundations" (specifically DE MELLO, V.F.B., 2180-2200), XII ICSMFE, Rio de Janeiro, Vol. 4, 2177-2227.
- VAUGHAN, P.R., and SOARES, H.F. (1982). "Design of Filters for Clay Cores of Dams", Journal of Geotechnical Engineering, ASCE, 108 (1), 17-31.
- WITTMANN, L. (1979). "The Process of Soil Filtration: its Physics and the Approach in Engineering Practice", 7th ICSMFE, Brighton, Vol. 1, 303-310.
- WOLSKI, W. (1965). "Model Tests on the Seepage Erosion in the Silty Clay Core of an Earth Dam", 6th ICSMFE, Montreal, Vol. 2, 583-587.
- WOLSKI, W. et al. (1970). "Protection Against Piping of Dams Cores Made of Flush Origin Cohesive Soils", Xth ICOLD, Montreal, Vol. 1, 575-585.
- ZASLAVSKY, D., and KASSIF, G. (1965). "Theoretical formulation of Piping Mechanism in Cohesive Soils", Geotechnique, ICE, 15 (3), 305-316.
- ZWECK, H., and DAVIDENKOFF, R. (1957). "Etude Experimentale des Filtres de Granulometrie Uniforme", 4th ICSMFE, Vol. 2, 410-413.