# CREATING AND COPING WITH CONTINUAL CHANGE, WITH CARE, IN CIVIL-GEOTECHNICAL ENGINEERING.

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## 1. Tribute and preamble.

I have been honored by the election to present this Lecture and technical contribution in homage to a dear and distinguished colleague, Eng. Francisco Pacheco da Silva, who was called to rest prematurely after having dedicated his unstinted efforts to the all-important infancy of Soil Mechanics in São Paulo (its principal cradle) and Brazil. We worked together with zest, cheer, and hope/certainty of progress, in the early days of the BRAVE NEW WORLD (immediate post world-war II), and we were such good friends that our earnest technical disagreements resulted creative. I remember two points of DOGMA and STANDARDS on which our debates led me to change course in my local career: for, as geotechnical engineer of COBAST (LIGHT, 1950), I ordered all testing done by the Institute of Technological Research (I.P.T.). For determining the permeability of compacted clayey specimens Pacheco insisted on using the U.S. Bureau of Reclamation (USBR) "conventionalized" (not to say standardized) procedure of using directly the specimen as compacted in the mold, whilst I remonstrated that it involved (in my mind) two undesirable features: the interference of the preferential plane of contact specimen-metal, and ignorance of the "triaxial" stress state[1]. In the following step further, in the (world) pioneering efforts to check on the (presumed) "(full) saturation" of soil elements in a dam core, we both had the rudimentary intuition of using seepage of deaired water[2] ; but, again, Pacheco would be satisfied with saturating within the metal mold and using high gradients, whilst I felt that would be treason on my geotechnical principles because of seepage stresses and fixed diameter, so I insisted on using long-term, moderate gradient, seepage in specimens controlled in "triaxial" steel chambers. Thus resulted (greatly abetted by the immeasurably gratifying testing enthusiasm of Prof. Odair

[1] I was happy dominated by Taylor's STRESS-PATH emphasis, hadn't yet reasoned on stress-strain-time-path, nor on the concept that "Stress is a Philosophical Concept; Deformation is a Physical Reality".

[2] Prior to back-pressure saturation, of around 1958.

Grillo) the decision to set up GEOTECNICA'S laboratory (PRIVATIZATION); so that when I first visited Skempton and Bishop in late Feb. 1956, I began to be introduced around "Meet Prof. Victor de Mello. He says he has 45 triaxials continually at work!", in comparison with most University and Company laboratories that had a couple of triaxials, only.

Well, good old days, of fertile quest, and developmental zest... not at discovering the back face of SATURN, or the DNA of the amoeba! Those were fruitful days when we had the obligation to know that we didn't really know, and our Clients trusted that we knew! Now we cling to what was taken as known, and our CLIENTS outdo us at it, because they remember and "know" even better our erstwhile secret POTIONS and PRESCRIPTIONS. Privatization presupposes a MARKET, which presupposes significant differentiation between suppliers and CLIENTS! Regretfully, in dedicating this effort in homage to Pacheco as a questful lover of all the undecipherable feminine secrets of individual soils and specimens, I feel bound to unveil, choosing a topic in which a mythical Helen of Troy, or Cleopatra, has been seized and enslaved, by well-meaning non-geomechanical generalists obliged to pose as Herculean victors of all tasks. The fault is greatly ours, of a geotechnique secured behind fortified walls, deprived of zestful forays, and balanced proportions of courageous/confident DECISIONS DESPITE DOUBTS, and DETERMINATION, nurtured by DIAGNOSIS, and DIFFIDENT DEDICATION TO DEVELOPMENT.

The message I feel prodded to put forth is of earnest concerns on the present stance of amnesic bewildered Geotechnique after her initial resounding victories[3]. Only three examples are used, in increasing order of attention, in the midst of several others analogously evident. Firstly, the bane of BIDING RESPECTFULLY BY OLD STANDARDS. Secondly, after musing on the freedoms taken, and given, (individually and in separate "schools") to transform conjectures into dictates, **on dormant distant problems**, and reaching dismay at **widely disperse PREDICTIONS vs. PERFORMANCE CHALLENGES** in well-trodden routine problems, stopping at a summary query on the persisting ignorance on **CLAY CONSOLIDATION SETTLEMENTS,** topic that heralded

[3] ref : Toynbee "A study of history"

the birth of the New (conventional) Soil Mechanics. And thirdly, for still modest but broader expatiation, the topic of ROCKFILL DAMS, CORE AND CONCRETE-FACE, a geomechanical child-orphan, since the behaviors of rock and gravel fills lie far beyond the capacities of laboratory or moderate-size field testing. Thereupon, ever greater should be our zest and responsibility of pressing for **appropriate mental modelling**, progressively adjusted hand-in-hand with well-designed index tests and specific field testing plus prototype instrumentation and monitoring, such "designs" being oriented along theorizable intuitions, indispensable both for profiting of the lessons for the on-going dam itself, for extrapolation to its later phases and requirements, and for meaningful extrapolations to future projects with different rockfill qualities. It would seem strange to see reputed and cognizant Civil Engineers still emphasizing a presumed dichotomic distinction between "theoretical"and "pragmatic"as in "The design of the CFRD being based on experience, can be considered to be empirical. Empirical is defined as guided by practical experience and not theory".

The fact is that practices, consequent results, interpretations, theorizations, and progressive intuitions for preservation or evolutions of practices, are **dominated by our biases in thoughts.** And these must be recognized, faced, exposed, and removed, as stumbling-blocks to development, forever awaiting and beckoning.

## 2. The bane of BIDING RESPECTFULLY BY OLD STANDARDS.

All technological STANDARDS are, ipso facto, established relatively early in a professional effort, and should be viewed as a REFERENCE FOR UNIFORM COMMUNICATION AND COMPARISON. Some Societies have a bias towards embracing them as saving dogmas, and especially so if they come "from above". Adherence to Standards is embraced as a defense against obligations to face varied and rapidly changing realities: but, what an illusion! Fig. 1 is reproduced to show how archaic can be some "updated" STANDARDS, and how such aged indications can understandably prevail in Societies that took the lead earlier. The point is that their professional leaders seldom exert themselves to revisiting older communication practices, and rely principally on their progressing experience[4]. How does our turtle-speed of 1946 -'99 compare with other scientific-technological leaps exponential? SHAME.

3. CLAY COMPRESSION, CONSOLIDATION AND SECONDARY CONSOLIDATION.

The subject of COMPRESSION and CONSOLIDATION, and of so-called SECONDARY COMPRESSIONS, opens an important threshold, both because it was the baptismal topic of Terzaghian pioneering "effective (intergranular) stresses", because its concerned academic bifurcations have greatly swerved from professional problems, and because it surprisingly links angular rockfills (with high instantaneous intragranular "point" stresses) and clays. The latter point serves as a good example of behaviors akin, "asymptotically culminating or not", capable of throwing some light on one-another. In clay consolidation its time remoteness ("secular") , permitted it to lie dormant, of secondary importance. But in rockfills, the immediacies of effects provoked concerns because of magnitudes of consequence. And on closer scrutiny (expatiated in a concomitant paper, DE MELLO 2000) we find that for buildings on clays architectural requirements have considerably tightened the professional needs, especially for deferred settlements affecting expensive finishes and precise industrial equipment, and meanwhile academic research and theorization to correct Terzaghian simplifying assumptions on purely vertical consolidation seem to have left buildings by the wayside.

So frequently surprising have been the results on challenges of geotechnique's ability to really predict meaningful behaviors, as shown in the table of Fig. 4 that it behoves me to start with one exemplary case (Fig.2). It exposes how the earliest "sufficiently quantified intuitions" (for 1925-55) (a) served their engineering purpose of the time (b) could have maintained the stimulating alternations of the yin and yang states, but (c) could and did open a destructive rift between academia and profession, leading to present sterility. Moreover it serves as a notable example of knowledge ever elusive on asymptotically culminating behaviors, for my **leit motif** of exhortation for Brazilian geotechnique.

[4] Premature adoption of standards for communicating reference (inevitable and useful) should never hinder progressive updating, with duly correlative (statistical) passing of the baton.

In Jan.1983 Schmertmann (ref. 2) put forth a challenging " Simple Question about Consolidation" put to "40 geotechnical engineers prominent for their research and work with soil consolidation..." and received 32 most surprising replies. The question should be curiosity-pregnant to academia "Does the effective lateral stress in...normally consolidated cohesive soil,... in the oedometer test, **increase, remain the same,** or **decrease**, during secondary compression aging ? "; its alternate stress paths are shown on Fig.2, together with tabled resulting replies. It serves herewith for an earnest call to discard unhesitatingly, on the spot, such primordial recommendations as, upon updated reconsideration, fail to satisfy some degree of **behavioral logic and/or prescriptive usefulness**.

Would it be unfair to postulate that in the face of priority challenges of the day, the QUESTION put forth would have been really a near-enigmatic side issue as regards CONSOLIDATION, for SETTLEMENT PRIORITIES (magnitudes, differentials and rates) [5]? The many more pertinent points of interest for foundations of buildings above clays are covered in a companion paper, and herein summarized in Figs. 5, 6A , 6B.

Fig. 5 summarizes fully known principles and practice on OEDOMETER tests, homogeneous soil elements to represent a presumed homogeneous clay layer thickness under constant (infinite area, I = 1.00) pressure increment p, and suffering modest (small strain) settlement with zero lateral deformation. The complement of using impervious base adapted for pore pressure measurements (unquestioned), and Constant Rate of Strain (CRS), has been a development widely sponsored. For double drainage the routine has been to use mirror-image behavior at mid-level. Regarding DRAG FORCES DOWNWARD in the lower part, and, in subsoil (as compared with test thickness) the varying parameters and consequences with depth, curiosities abound. Fig. 5 (d) summarizes keyword reminders regarding TEST PARAMETER EXTRACTIONS ; since the intromission of some shear in oedometers was early recognized as inexorable, the use of Skempton-Bishop (1954) A, B, $\bar{B}$, parameters or analogous-updated (cf. Skempton and Bjerrum 1956) for better Δu quantifications is needed, principally when transferring to field

[5] Would it sound Cassandran to forebode with Churchill that "the trouble with the Chiefs of Staff of all armies is that they always study well how to fight the last war", or with Toynbee, that the decay of Societies accompanies the tendency to "rest their oars" right after resounding victories. This is an example of one vital problem of foundation engineering which, SO WELL RESOLVED IN FIRST APPROXIMATIONS, permitted geotechnicians to "rest their oars", work in circles of compensating errors,

conditions[6]. Fig.6 further summarizes a view on the salient historic developments, that dispense expatiation. Finally Fig.7 exemplifies in FIRST-ORDER QUANTITATIVE APPROXIMATION a typical problem of a building on shallow foundations, for instance, in Santos.

It can be seen that the rate of settlement problems are very much more complex than hitherto solved, to my knowledge, even when disregarding completely any intromission of secondary compression. Needless to say, directions and gradients of $\Delta u$ dissipation follow from higher to lower u values, but rates of settlement depend on gradients and drainage distances and very much on the curve of $\Delta V$ volumes of water to be squeezed for final "stabilized" effective stresses. It transpires that a significant lower part of the stratum will have very slow primary consolidation.

The primordial subject of long-term settlement predictions of compressible clayey sites, and progressive updatings, calls for important ENGINEERING PRINCIPLES regarding the needs of (1) humility and prudence in the face of ever-singular soils (2) increased questioning on primordial "deterministic" tests and theory-fitting (3) increasing respect for theorizable procedures for establishing statistical adjustment factors for extrapolating, from laboratories and small-scale early field tests and indices, to final prototype behavior, and from one prototype to the next. In view of recent very reputed publications (Refs. 3, 5) I find it necessary to reemphasize (Ref. 4) the needs both to revise test parameters under improved techniques (indexed as to SAMPLE QUALITY) as also frequently to discard into oblivion (minimal gesture of respect for the future and its economy) some well-intended practices. Fig.3 gives an example[7], of the surprising degrees of unknowns revealable by successive updated procedures.

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and disperse into academic and mathematical inquiries of relative sterility, while "know-all" structural engineers occupy the field.

[6] Compositions of oedometer deformation-controlled (more or less) and triaxial stress-controlled behaviors embodies some practical errors of feasible corrections.

[7] As expatiated in (Ref.) adequate interpretative procedures must guard against suspicions (a) "initial installation conditions" (b) instrumentation-adulterated effects on the prototype (c) assumed " ultimate conditions" (d) generalizations for "all materials" except inasfar as "acceptably useful" as a Prescription of first-order for practice. For instance, the Casagrande method for determining $C_v$ that fails on every count should have belonged to oblivion long since, as were the Sun and Moon deities (useful) of primordial civilizations: meanwhile, as for the CRS single-drainage oedometer method employing continuous preservation of an " insignificant" residual pore pressure at base, it implicitly incorporates a continual parcel of secondary compression together with the primary complicating the issues of researching different time laws for transfer from laboratory to prototype; and the reconstituted-slurry method(Burland, 1990) implicitly permits neglecting colloid-chemical singularities both in flocculated sedimentations ("structure", Casagrande 1932) and in potential subsequent thixotropies.

These admonitions, arising from clays, are of pointed significance also for angular rockfills because the aims are: estimating really applicable lateral stresses (non "normally compressed" $K_o$) and respective changes, behaviors as "secondary deformations" post-instant self-weight compressions, and these to be deduced from self-weight "primary" monitored compressions, duly expurgated from installation and instrument self-adulterated effects. No greater challenge could geomechanics face for earnest service.

Fig.7 shows blatantly (from Foz do Areia dam) the fully recognized differences between what matters and is sought, and what is easily obtained. In the oldest problem of geotechnique the historic difficulties of measuring instant $\Delta u$ etc. have been resolved, but the real obstacle is that we have **rested our oars**. In the case of rockfill dams the difficulties of realistic prototype testing left a vacuum from which we fled. In all cases we recognize that the inability (temporal) to tackle a priori testing permits and leads to the success of problem solving by a-posteriori data-fitting (of relatively few and analogous cases) to which ANY THEORY BECOMES AMENABLE : and so, in a vicious cycle, a success becomes fatal to development.

Are we timidly confining ourselves only to old Standards and Codes uninterpreted, and to what is easy (rather than what is most necessary) to do (irrespective of usefulness vs. cost-waste ?). As a final blow to those who would seek such demeaning comfort I should close this preamble with the mercy shot to indolence.

Let us return to Fig.4, of a tabulation of the results of some of the most published international challenges of significant professional problems, some of them presumed (and systematically taught) as resolved long-since, in theory and practice. The individual cases have been expatiated somewhat (de Mello 1999) and really merit workshops of scrutiny in their bases. The net conclusions of great professional-social impact can be given as: (a) the inordinate number of theories and procedures employed, by very knowledgeable colleagues. For instance, whereas in Structures or Hydraulics one would find 1 or 2 theories in use, in Geotechnical Engineering we find as many as, say, 20 theories/methods employed by 24 different predictors; (b) the incredible dispersion of so-called "Factors of Safety FS" calculated, in almost all cases about 5% of the PREDICTORS anticipating "failure" at the measured working load, as opposed to a similar number of overoptimists predicting behaviors as good as 10 times better than observed; (c) on average the would-be design resulting over-conservative[8] (therefore unnecessarily more expensive); (d) an impression that the "safety margins" achieved by conventional FS numbers, imported unquestioned from STRUCTURES, often have little significance on pertinent behaviors that have shifted from FAILURE – dominant to DEFORMATION-concerned.

In concluding these comments, I feel deeply the responsibility of redressing the socio-economic importance of advancing geotechnical engineering. Taking Brazil´s present population at 160 million, and a goal of population plus quality-of-life increment of only 2% per year, we could estimate that a 30% reduction in costs of merely the civil-geotechnical part of (a) hydroelectric works (b) water-supply (c) foundations of building structures[9], would entail a yearly national saving of over 1.4 billion dollars!

The challenge is there: what might be the response, in concerted efforts ? Let us train at the exercise via our ROCKFILL DAMS, CORE AND CONCRETE-FACE (Fashions, dead-end, or earnest geomechanical perspectives?)

## ROCKFILL DAMS, CORE AND CONCRETE-FACE.

**(Fashions, dead-end, or earnest geomechanical perspectives?)**

Introduction

[8] Together with conclusion (b) this reflects the commendable engineering principle of prudence associated with ignorance and uncertainty, which would not be expected after 75 years of geotechnique. Incidentally, the experience record of building foundations and dams tallies with the impression of dominant over-conservatism in practice.

Interest in the use of compacted rockfills for optimized layouts of dams has increased exponentially for merited reasons. The principal optimization necessarily starts from the many alternate first-order layout studies, wherein **dominant considerations pertain to the three hydraulic circuits, diversion, operation, and spillway**[10]. Moreover, cogent reasons of urgencies of satisfying supply, and needed speed for minimizing first-costs and interestaccrued, have emphasized conditionings by hydrology, hazards, and risks, principally for construction phases, and improved constructive expedients. Concomitantly there is the assertion that concrete-face rockfill dams CFRD are indestructible (and earth-core ECRD also nearly so), their present design features being focussed on fringe details to avoid inconvenient seepage losses. Thus quite logically the recent advances and publications have been by layout-hydraulic-generalists, and creative construction-cost-logistic engineers. The only questions posed concern the anticipations regarding different sites and rocks, and eventual novel conditionings as increased heights come into play.

The purpose herein is to retrace the history, once again (cf. Refs.....) but concentrating on rockfill geomechanics and its lessons learnt, including those shamefully set aside or meriting improved quantifications. An attempt is made to refer to publications and experiences in chronological sequence, even though understandably some practices and principles evolved without the presumable interplay between widespread sources in due time. A thread of continuity is established in accordance with basic concepts and functions of the dams' components. It will be noticed with no small surprise that although the fill represents over 90-95% of the dam's costs and is the source of prospective problems causable, attentions to flagrant geotechnical problems of the compacted fills have been suppressed, becoming totally focussed on peculiarities of the slab and joints, and their construction logistics: and

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[9] Excluding ports, highways, subways, etc...

[10] Regretably most papers on dams stay shy of any mention on hydrologic conditionings and end-purpose, whilst in the specific case of both CFRD and ECRD dams, and especially in the cost comparisons between the two, the diversion circuit with cofferdams becomes a prime feature. In the ECRD the US cofferdam is optmizedly incorporated, but in the CFRD it becomes a transiently needed feature (totally wasted after partial raising of the dam) which directly affects the diversion tunells. Comparisons of how fast to raise the temporary partial US sections of either dam, and how to accept comparable hazards risks of low-probability overtopping during construction without major damagtoDSrockfill shells, becoming the crucial questions of intertwining between hydrologists and geotechnical engineering's creativities.

even ironically further, when slabs risk or evince defects by cracking, it is to presumed geotechnical remedies that the slab-engineering resorts, entrusting responsabilities to quite questionable degrees.

2. Basic starting reference, J.D. Galloway, Oct.1937.

Rockfill dams developed since around 1860, and mostly in California, a known highly seismic region. One must note the clear starting statements: (p.2) "Many have been constructed that have given years of service and are to be considered entirely safe"; and "are composed of three elements: a loose rock-fill forming the mass of the dam; an impervious face next to the water; and a rubble cushion between the two". Foundations, generally appropriate by site selection, were not conditioning, thus acceptably not mentioned.

Attention is firstly drawn to the mostly surprisingly steep slopes (Fig. 1), stable through several decades. Note the general claim (P.10) of "water-face which is mostly 1:1" and has decades later been significantly flattened for side reasons. Part of the explanation lies in the low dam height, profiting of the curved rockfill strength envelope[11] (Leps) and critical destabilization at face ("circle" of infinite radius) which occurs as ravelling of some rocks. Note (p.12) "In any slope steeper...it is necessary to carry up this rubble facing with the loose rockfill **in order to retain the latter**", recognized as "**comparable to masonry walls**" (p. 14). And in part it shows that a thin face cover of dry hand-arranged rubble achieves and imparts amazing stability mostly because of the rock-block contacts, nearly face-to-face, corresponding to extremely low normal intragranular stresses. Although the two stated purposes of the shallow dry-rubble facing were quite other, it really stands out that one of the two principal results was of greatly increased stability. Experience with vertical hand-placed facial masonry was age-old, ample and evident calling for interestd query because of very many monumental medieval walls. In many a dam, the breakage of stones (along diaclases) by tractor threads plays such a stabilizing role (cf. Furnas) in the dam body itself, forcing

[11] It should be noted that for most potential slope destabilizations the applicable displacement-stress path involved should be one of stress release from a stabilized condition. And, due to inevitable hysteresis, this implies a somewhat higher curved strength envelope than the conventional one based on tests exclusively under increased loading. It is regretable that testing routines rarely investigate, or use, this advantage of undeniable incremental stability (de Mello...), merely because of non-specialist inertias of

an about-turn distinction between blocks first broken, then spread and compacted with point intragranular contacts, and those spread in the lift and then cracked face-to-face in situ (simulating stable area contacts akin to hand-placed masonry).

The **cushion effect**[12] was clearly desired and effective in avoiding high localized stress redistributions onto point supports, or wider-span supports, under water loading of the concrete slab. However, the stated aim of decreasing water load deformations by being denser, less compressible, can be seen to be illusive by comparing the compression of the thin cover versus its high and thick loose rock "subgrade". Recognizedly for the modest historic water pressures, the comparative increment of rigidity cushion-plus-concrete versus merely concrete was unquestionably favorable.

These points must be recalled, in modified perspectives, when discussing modern high compacted rockfill dams and the respective different "cushions" in use.

In the appraisals of historic cases some of the incomprehensibly steep slopes (e.g. First Fordyce, 1873, 23m) may be pardonably explained by comparison with dry-rubble[13] masonry gravity sections (without mortar), having a base width of 0.8H (with US/DS slopes of 1:0.55/0.25 V:H) and some luck. Moreover, without delving into details of diminishing returns of very old records, it is fair to estimate that all the rocks were sound, of the "ringing quality" (cf. Disc., p. 31), with no fines.

The author foretells that "The natures of the rock-fill is one upon which difference of opinion will develop" (p.9), indicating that "the fill should be composed of individual rocks of fairly uniform size", one rock bearing directly upon another, usually expressed as "rock to rock". Any wide divergence in size will cause

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thinking of constant of sands, neglecting to update to curved envelopes, hysteresis, and stresses accompanying "failure" displacements.

[12] Subdividable into (a) decreasing global settlement-deformations (b) distributing homogeneous support contact stresses (c) increasing "base" rigidity for wider spans between slab supports.

[13] The term "rubble" of the time is not to be confused with loose dumped rockfill, especially considering the manual labour, limited equipment potential, etc.

excessive and unequal settlements". This must be understood in the proper context, of volumes of different-size rocks side by side, and not in the context of a non-uniform grainsize of rockfill, as is presently preferred[14], for the self-same effective reason, intragranular (vs. face-to-face) contacts.

The recommendation of "constantly washing the fines into the rock (with 100 psi fire streams) belonged to some intuitions that have been aptly revised over the past score of years, under the vastly revised design-construction techniques. Indeed the sequences of sandwich sublayers per lift (upper with more fines, favorable for traffic, and lower for big rock) are recognized as inexorable, but the conclusion that "such a layer of small material invites large local settlement, especially when the water load is applied" can only be justified as connected with uncompacted and thicker layers of fines. "It is realized that a heavier mass will result if fine material can be washed into the interstices of the fill", but material washed-in after the coarse-rock structure has been established and accomodated, is really quite inconsequential even as concerns weight. "Such a course is advisable, only after the fill of rock has been made" is immaterial as regards weight, not transferable to the coarse rock-rock structure.

What escaped being noted is the possible effect (in most rocks and dam heights, to different degrees) of the wetting of rock-rock angular intragranular contact stresses, towards increasing the settlements due to crushing.

One continues to note principal concern with the rubble cushion, rising with the loose rockfill faster, for "time given for the loose rock to settle". Slab details were minimal, including (p.13) "to make the upstream slope a curve concave to the water. This prevents buckling of the concrete facing under the settlement. Usually, the result is obtained by varying the slope (flatter at bottom), achieving a warped surface" . Concrete slab steel principally for "temperature changes" (p.16), pouring concrete "directly upon the rubble wall, taking care that interstices are left in the rock work into which..to **secure a firm bond** between the two elements. In addition, grooves or chases should be built in the rubble at the joints, thus giving a closer bond". Considering the much greater variabilities of settlements and water-load displacements accumulated in recent times, and the recognition (Disc. P.25) " The

[14] With regard to uniform vs. non-uniform grainsize curves of rockfills, and the widely different conclusions to be associated with different types of non-uniform curves, and their illusory vs. effective dry

statement that the horizontal joints will always be in compression is quite debatable", it seems preferred to allow the slab to slide somewhat on the cushion.[15] (P.20) "It might be questioned whether the concrete should not be formed **so as to be separated from the rock in order to permit movement**"[16]. Partial river closures not considered, the generalization prevailed that "movements of the rockfill under settlement are toward the center of the dam from the flanks, the joints in the central portion will tend to close and those at the abutments will open".

Nihil novum sub solem! Regarding angle of repose as determining stability, Disc. P.45 poses "depending on what is meant by a "natural" slope; whether it is the slope on which the **rock will stop moving when dumped, or the slope on which, when at rest, the rock will start moving**; or even further, (Ref VFBM) the angle at which a **dumped stockpile stays stable when excavated**". These elements of design were readily noticed. But the principal concerns for slab design were long awaiting. At the time (Disc.P.55) "the only data available with respect to settlement of rockfill dams was for the **settlement of the crest**"; internal settlement measurements during increasing rockfill overburden were still a score of years in the offing, and the question of how to relate these to the displacements of the face under reservoir load are still a challenge. But the understanding (Disc. P. 28) "The cause of settlement in a loose rock mass is mainly **crushing of the individual rocks at points of contacts**" having been unchallenged, the difficulty (and consequent lack of initiatives) lay toward creating moderate quantifying indices for prediction. Thus the suggestion that (Disc. P.42) rocks should be "dropped into place from heights greater than 10 ft, to **hammer rock into place**" (but no comparison with compactors), and debates on well-graded non-uniform grading (Disc. P.38, 40,41) rather than same size, sluicing or not, sluicing to "fill interstices" (clearly innocuous) vs. sluicing to wet point contacts. Regarding rock sizes from the same quarry one conventional intuition assumed (Disc. P.42) "Large rocks are least damaged by quarrying", an apparent reshuffling of "quarries of best quality rocks give large rocks" since it has been reasoned, by "natural selection" (Ref) that from a given jointed rock quarry the largest fragments are those broken along the weakest discontinuities, and so progressive comminution leads to

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densities, important undisputable provisos are expatiated in.....

[15] The thought would raise interest in the possible use of a thin geomembrane as cover element of the cushion in lieu of multiple accrued details.

[16] It is not difficult to perceive that as the rockfill support compresses, and the face-slab deffects, increasing in length in general, even if locally led to compressions, the great differences of concrete to rock deformability MODULI should require permitting slippages to minimize cracking.

progressively more resistant cores. (P.52 Disc) affirmed "all authorities appear agreed....plentiful sluicing......facilitate and accelerate settlement", but for lack of tests and observations no predictive connection was sought with the ratio of dry/wet unconfined compression strengths (or other such indices) nor of the degree to which the increased settling capacity would benefit or hamper the really nevralgic prediction and performance, of displacements caused by reservoir loading. Some of the discussions provided qualitative data on different rocks, some sedimentary (softer), but the concomitant tendency to greater fragmentation, and subsequent denser packing masked considerably the clear understanding, of **intragranular rock-rock stresses of the effective structure**, and the illusive increasing density due to ineffective appended grains washed-in/out of interstices, causing a change of index without any possible consequence on behavior (cf.)

3. Rockfill behaviors, tests, observations, and intuitions: fundamental inquisitiveness followed or neglected.

Moving on from this milestone, it becomes convenient to discuss separately the CFRD and the ECRD firstly with regard to rockfills and granular transitions, whose behaviors, mostly equivalent, created different problems and detail solutions because of interactions with the impervious element.

Although to geotechnical engineers, who would view only the embankment dam, it would seem that the competition should favour the CFRD because of the face-slab im comparison with the wider and more complex composite sequence of core-and-transitions, the real vantage points in one direction or the other are much more influenced by hydrology, meteorology and construction logistics. In consequence it may be said that the sclerosis of conventional geotechnique has been a bane to the ECRD of their preference, while the know-all simplifications of layout experts has been the hindrance to the CFRD of their sponsorship.

The hydrologic conditioning achieves significance depending on the US cofferdam, not incorporatable into the CFRD, thus increasing the lengths of diversion (and possibly power) tunnels. Meteorology influences the rate of rise of compacted core and transitions in rainy weather. But truly, after diagnoses, the interative optimizations between hydrologic decision, channel and /or tunnel hydraulics (straighforward) and geomechanical conditionings of tunnels and/or fills, should surely invoke dominant conditioning by the most subservient and complex components, which are undisputably GEOMECHANICAL, including Contractor's logistics and plant.

The competitive points will be broached after the priority collation of information on rockfills, reliant on inquisitive quests in field practice and comparative performance observations. Note that such inquisitiveness is really quite inexpensive financially, merely hampered by mental and institutional lethargy: for instance, what incremental cost is there in using in the same embankment, side by side, monitored sections with different rock qualities or different compactors, thicknesses, rock sizes, etc..? We shall perceive the sore dearth of evidence applicable for logical technological advances; meanwhile it will be seen that with but little expense the largest proportion of relevant data may yet be retrieved from existing dams. It would seem that for a considerable period the lack of means to test rockfills appropriately, and the retarding of means to apply field testing, instrumentation and monitoring of internal behaviors of the comparative geomechanical volumes retained greater freedom of trial-and-error activity in the CFRD alternate, with the rock's unforeseen virtues minimizing the errors towards relative impunity. The present edge in favour of CFRD is somewhat increased by the pessimistic testing and theorizing on fine soils for the cores, and corresponding multiple transitions that burden the ECRD.

It would seem ironical that the lack of knowledge, testing, and theorizing, has permitted many **variations of fashions on geometric sections** (Fig. 2) of high CFRD dams, while so-called precedents (geometric) accompanied by **first-order tests and theories have set back the ECRD,** for the very reason that soil specimen tests were presumed applicable to coarse granular fills.